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The present volume contains the contributions from the Woods Hole Oceanographic Institution which appeared during 1941 in publications other than *Papers in Physical Oceanography and Meteorology;* also the Annual Report of the Director for 1940.

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BY HENRY C. STETSON

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OCEANOGRAPHY

INTRODUCTION

Oceanography is a young science and in the modern meaning of the term includes not only the study of the physics and chemistry of the sea water itself but the animals and plants that live in it, the sediments which have settled out of it together with conditions governing their transportation and deposition, and the topography and geologic structures of the various basins which contain it. Inclusiveness, however, is not solely the result of youth, for by its very nature the different branches will always be closely interwoven. For instance, the problems of the chemist also concern the biologist studying the ecology of animals in the sea, and they will also be of importance to the geologist if an adequate attack is ever to be started on the diagenesis of sediments. The forces governing the different types of currents are of interest to physicist and geologist alike, and it has recently been demonstrated that some of the principles of oceanic circulation are equally applicable to the atmosphere.

The different divisions are further tied together by the purely practical necessities which the study of the ocean imposes. A seagoing vessel is expensive to acquire and to maintain, and in addition there is the cost of the special equipment which a research ship must have. An investigator whose field work is carried out by such costly and time-consuming methods has little choice but to work in conjunction with others whose data likewise must be gathered by the same means.

Surveying, sounding, and charting have always played a part in oceanographic expeditions, but, until recently, geological work has been secondary. Small bottom samples were taken in the course of routine sounding, and a generalized knowledge of the areal distribution of the oceanic sediments was early acquired, but here the matter rested. However, before tracing the growth and development of the geological branches of this science, it is necessary to review the beginnings of the subject as a whole.

HISTORICAL BACKGROUND

BIRTH OF THE SCIENCE

On December 21, 1872, H. M. S. *Challenger* sailed from Portsmouth, England, on what proved to be one of the memorable voyages of history. It lasted 3½ years, circumnavigated the globe, and investigations were carried on in every ocean except the Arctic. It was the first combined assault on the ocean with all the techniques which were then available. Nothing approaching this undertaking in detail and completeness had been attempted heretofore or even contemplated. At each station the

following observations were made insofar as practicable: The depth was determined and a bottom sample taken; serial samples of water were obtained from the surface to the bottom for chemical and physical examination; serial temperatures were taken from the surface to the bottom; a fair sample of the bottom fauna was dredged, and samples from intermediate depths and from the surface were taken in tow nets; atmospheric and meteorological conditions were noted; and the direction and rate of the surface currents were observed, and at some stations attempts were made to ascertain the movement of the water at various depths.

The initiative for this undertaking was furnished by the interest and enthusiasm of two British naturalists, Dr. W. B. Carpenter and Prof. C. Wyville Thomson. A few years before, through the influence of the Royal Society, the Admiralty was persuaded to fit out an old gunboat, the *Lightning,* for a dredging and sounding trip in the vicinity of the Faroe islands. Biological dredging was carried out in a little more than 600 fathoms which was a record for that time. This voyage proved so successful in spite of bad weather, limited equipment, and a poorly found ship that in 1869 the Admiralty was again persuaded through the same channels to fit out another ship for similar purposes. The *Porcupine* was a better vessel, and more extended cruises were taken around the British Isles, into the Bay of Biscay, and the Mediterranean. Successful dredging was carried on to over 2400 fathoms and it was all done with hemp rope. On these cruises temperatures were taken at various depths on the dredging stations. Having demonstrated the feasibility and the scientific importance of this type of research at a time when attempts to lay transoceanic telegraph cables were drawing attention to the ocean basins because of the need for more accurate knowledge of their topography, the moment was opportune for projecting a major expedition.

Wyville Thomson, who was knighted for his leadership of the expedition, died a few years after its return, and the task of preparing the reports fell to John Murray. The 50 quarto volumes, with many specialists contributing, are evidence of the huge quantity of data collected. Although the publications in biology bulk by far the largest, nevertheless considerable geological information was also obtained. The depths and main contours of the ocean basins were determined for the first time, and the general distribution of the bottom deposits was mapped. Many out-of-the-way corners of the world were charted, and something was added to our knowledge of ocean currents both on the surface and at various depths. Pioneer work was also accomplished in the field of hydrography and on the chemistry of the ocean. Today it is, of course, easy to pick the flaws. Methods in every field have become more precise; improved

gear has been developed as well as more exact procedure. Nevertheless, theirs was the pioneer attempt, and with that voyage the broad framework of the science as a whole was laid down to remain scarcely altered until modern times. Others have profited by their experiences and improved on their results, but, taken by itself, no other subsequent expedition has left so deep an impress.

Interest was so stimulated in other countries that a succession of deep-water expeditions to various parts of the world followed. By 1900 the United States had sent out *Blake, Albatross,* and *Tuscarora;* the French, *Travailleur* and *Talisman;* the Germans, *Valdivia* and *Gauss;* the Italians, *Vettor Pisani;* the Danes, *Ingolf;* and the Dutch, *Siboga,* and this by no means completes the list. None of these cruises was so extended as that of the *Challenger,* and although the gear was constantly being improved the work was laid out along essentially the same lines. Although the expedition sailed more than 50 years ago, the voyage marks the birth of oceanography as a science. Consequently some description of the vessel and her gear is pertinent as a background against which to view modern developments.

EARLY EQUIPMENT AND METHODS

Selected by the British Admiralty for this voyage, the *Challenger* was a corvette of some 2000 tons with auxiliary steam. The guns were removed, and she was refitted in various other ways for her new purpose. She still remained a navy vessel, however, and Captain George S. Nares, an officer of much experience in surveying, was given command. Prof. C. Wyville Thomson was in charge of the civilian scientists, and the work of the naval and civilian staffs was kept separate. Thomson (1877, p. 11) writes of the voyage:

> "the chart room . . . is a commodious compartment on the starboard side with ranges of shelves stocked with charts and hydrographic, magnetic, and meteorological instruments. All work in these departments, as well as the whole of the practical operations in dredging, sounding, and taking bottom and serial temperatures, is conducted by the naval officers."

The natural history work room corresponded with this on the port side, and a chemical laboratory was also fitted up. These were both in charge of the civilians.

All soundings were taken with a specially made hemp line wound on reels. The sounding instrument was a tube around which detachable weights were fitted. On striking the bottom the weights were released, and the tube was hauled to the surface with its plug of sediment or perhaps a short core. The line was marked off every 25 fathoms, and, in deep water, contact with the bottom was ascertained by the slackening in the rate at which the line ran out. All hydrographic work—that is, the taking of temperatures and water samples—was done with this same

line. Hemp rope 2, 2½ and 3 inches in circumference, and spliced in 3000-4000 fathom lengths, was used for trawling and dredging. Steam winches were used for hoisting, but even so the labor of handling and coiling the miles of rope required for the deep tows must have been very great. However, as warships always carry proportionally larger crews than other vessels, plenty of man power was available. It is interesting to note that with present-day equipment exactly the same work can be, and is, done by three men in a watch.

In 1872 Sir William Thomson, later Lord Kelvin, seeking an improvement in the laborious and not too accurate method of sounding with rope, developed a machine for using piano wire. The great disadvantage of rope for sounding is the frictional resistance it presents to the water. Not only does it take longer to run out than does wire, but the currents encountered often throw it into large bights making the sounding inaccurate. Kelvin's method with various modifications gradually came into general use, and up to the invention of echo sounding wire was used in all surveying. At the start, however, difficulties were encountered in securing wire of sufficient tensile strength and in making strong splices, and although the *Challenger* had one of these machines on board it was never used. It is interesting to note, however, that only 2 years later Lieut. Commanders Howell and Sigsbee (1880) of the United States Navy adopted wire and used it successfully on the United States Coast and Geodetic Survey steamer *Blake* which they successively commanded. Sigsbee modified Kelvin's machine and invented another which bears his name, but the principle remained the same.

LOUIS AND ALEXANDER AGASSIZ, MONACO, AND NANSEN

Four individuals deserve special mention in this historical review for their unique accomplishments: Louis and Alexander Agassiz who were responsible for the inception and growth of oceanography in the United States, the Prince of Monaco, and Fridtjof Nansen.

Louis Agassiz's interests in the field of natural history were exceedingly catholic, and oceanography was but one of the many matters which came in for a share of his attention. Throughout his lifetime his relations with A. D. Bache and Benjamin Pierce, the superintendents of the United States Coast Survey, were most cordial, and his suggestions for projects which could be carried out from government vessels, in addition to their regular surveying duties, were always welcome. The man who was responsible for the actual dredging was L. F. Pourtalés, one of Agassiz' associates who had followed him from Switzerland to America in 1848, and who 2 years later became an assistant on the Survey. Today he is

comparatively obscure although he was the pioneer of deep-water dredging in this country and antedated the first English cruises. In 1869 he published a short account of the sediments of our east coast continental shelf, which is believed to be the first paper on modern marine sediments to appear in this country (U. S. Coast and Geodetic, 1869, Appendix No. 11, p. 220-225). Although Agassiz was primarily a zoologist, his interest in geological matters was always keen, and in a report to Pierce on the work of the *Bibb* in the Gulf Stream and off Florida and Cuba appear the following observations (1869, p. 368-370) which are of interest considering the date.

"From what I have seen of the deep sea bottom, I am already led to infer that among the rocks forming the bulk of the stratified crust of our globe, from the oldest to the youngest formation, there are probably none which have been formed in very deep waters. If this be so, we shall have to admit that the areas now respectively occupied by our continents, as circumscribed by the two hundred fathom curve or thereabout, and the oceans at greater depth, have from the beginning retained their relative outline and position; . . . Moreover, the position of the cretaceous and tertiary formations along the low ground east of the Alleghany range, is another indication of the permanence of the ocean trough, on the margin of which these more recent beds have been formed. . . . Geologists, and especially those of the school of Lyell, have again and again assumed the slow rising of extensive tracts of land from beneath the water, and taken all sorts of loose materials . . . as evidence of its former submersion. But since the dredge has been applied to exploration of the deep, and a great variety of animals, in a profusion rivalling that of shoal water, have been brought up, . . . no observer is justified in considering extensive deposits of loose materials as marine in which no trace of marine organic remains are found."

He made his last cruise in the Coast Survey steamer *Hassler* around the Horn from Boston to San Francisco in 1872 shortly before his death.

Oceanography is such an expensive field of research that few individuals have been able to finance their own investigations. Alexander Agassiz was one outstanding example, the Prince of Monaco was another. Agassiz' early cruises were made from 1877 to 1880 in the United States Coast Survey steamer *Blake*. It was on the first of these, only one year after the return of the *Challenger*, that Agassiz, with his background of practical mining experience, first introduced wire rope for dredging. The tremendous advantages over hemp rope—greater tensile strength for a given diameter, ease of handling, and ease of storage—are, of course, obvious, and its value for use at sea was quickly demonstrated. Nevertheless, considerable time elapsed before it was generally adopted in Europe. To Lieut. Commander Sigsbee (1880), the man who first successfully proved the entire practicability of sounding with piano wire by a modification of Lord Kelvin's machine, should go the credit for the proper installation of the winches and all the details for the practical handling of the dredging wire aboard the *Blake*. Sigsbee, it will be remembered, later was in command of the U. S. S. *Maine* when she blew up in Havana harbor.

The *Blake* worked off the east coast of the United States, in the Gulf of Mexico, and in the Caribbean, in shallow water and deep, and these cruises marked the most serious attempt in the United States, up to that time, to solve oceanographic problems. They were but the forerunners of Agassiz' many expeditions, as he remained active up to the time of his death in 1910. He chartered many vessels privately, and even when using the *Albatross* belonging to the United States Bureau of Fisheries he bore a large part of the expense of operation. His voyages took him into the Pacific and Indian oceans as well as into the Atlantic and throughout the West Indies. Although biology was his chosen field he took a lively interest in the coral reef problem and probably investigated more reefs than has any geologist. He added hundreds of deep-water soundings to the charts, and in certain parts of the Pacific they remain to this day the only ones that have been taken. It does not often happen that a single individual is able to further the development of his particular field to such an extent or to exert so much influence on it.

The Prince of Monaco became interested in oceanography as early as 1885 and used his own private fortune to finance his researches. He successively equipped several yachts for this type of work, frequently commanding them himself, and built a laboratory and museum at Monaco where the results of his investigations could be worked up and published. A long series of important reports and monographs have come from his institution, and oceanography has been greatly advanced by the efforts of this one man, particularly in the field of biology.

Nansen began his career as an oceanographer by planning and successfully carrying out one of the most remarkable voyages that has ever been undertaken. His idea was to freeze a vessel in the ice and drift across the Polar Sea, possibly reaching the pole itself. He was confident from the slight evidence available about the currents that this could be accomplished, although many predicted that he would never return. *Fram* was a heavily constructed, wooden vessel and of such design that, when squeezed in the ice, she would tend to lift and not have to take the full crushing force of the shifting floes which no ship has ever been able to withstand. She was frozen in off the New Siberian Islands in 1893 and emerged from the ice 3 years later off Spitzbergen. The pole was missed by less than 5 degrees, but many valuable hydrographic data were obtained through holes cut in the ice during the drift across the then unknown Arctic Basin, and the first bottom samples were secured. *Fram*, after several subsequent trips, is now preserved as a national monument at Oslo, like Nelson's flagship *Victory* at Portsmouth, England, and the *Constitution* in the United States, an honor which but few of the vessels that have made history have attained.

PROGRESS IN SUBMARINE GEOLOGY UP TO 1900

GENERAL STATEMENT

The turn of the century roughly divides the older from the modern phases of the science as a whole; consequently it is pertinent to give a brief summary of progress up to this point, before the advent of various new techniques which have put submarine geology on a par with the other subdivisions of oceanography.

MURRAY'S CLASSIFICATION OF SEDIMENTS

Up to this time most geologists had taken little interest in oceanography. They accepted Murray's broad and rather inclusive classification (*Challenger* Expedition 1891) of marine sediments without critical comment, as though sediments in the sea and sedimentary rocks on land were unrelated phenomena. The interest of the oceanographers, where sediments were concerned, largely centered in the oozes of the deep sea, and though plenty of shallow-water samples had been collected nobody paid much attention to them. Murray's classification became standard the world over and for that reason it will be restated here.

He lumped all marine sediments in two main categories—terrigenous and pelagic. The former group includes all sediments consisting of waste derived from the land. Once outside the zone of littoral and shallow-water deposits, which are supposed to cease at 100 fathoms, the terrigenous sediments covering the continental slopes and parts of the ocean basins nearest the land are pigeon-holed in five divisions. Blue mud is characteristically found in the neighborhood of continental land masses. Green mud is a variety containing glauconite and according to Murray's description (1912, p. 162) usually occurs

> "off high and bold coasts where currents from different sources alternate with the season, as off the Cape of Good Hope, off the east coast of Australia, off Japan, and off the Atlantic coasts of the United States."

It may grade into greensands. Red mud is still another variety

> "found in the Yellow Sea and off the coast of Brazil where the great rivers bring down a large amount of ochreous matter" . . . (1912, p. 162).

Volcanic mud and coral mud are self-explanatory.

Pelagic deposits begin to make their appearance in the ocean basins proper, at sufficient distances from the continental margins to prevent their being masked by detritus from the land. Of these, *Globigerina* ooze is the most widely distributed. Diatom ooze is characteristic of the colder waters, particularly the great circumpolar seas of the southern hemisphere; pteropod ooze is found in the warm waters of the tropics; and radiolarian ooze occurs in the deeper parts of the Pacific and Indian oceans. The last and most interesting of the deep-sea oozes is red clay, which floors vast

areas of the Pacific far from the continents. It is supposed, according to Murray, to be a hydrated silicate of alumina derived from the disintegration of pumice and volcanic ash. Its rate of deposition is extremely slow, and consequently it is found only in the more remote parts of the ocean where the deposition of other debris and planktonic material is practically zero.

Such, in general, is the horizontal distribution of the various types of marine sediments as determined from the *Challenger's* data. Subsequent expeditions merely defined the areas more exactly. It was worked out, in a sense, merely as a by-product of sounding. The samples, as we have seen, consisted of small plugs of mud brought up sticking in the end of the sounding tube, and they were so short that to all intents and purposes they were surface samples. During this period no one seems to have made any serious attempt to secure cores.

IMPROVEMENTS IN SOUNDING TECHNIQUE

The gear for deep-water sounding had been greatly improved as time went on, and with this development in technique came a corresponding increase in our knowledge of the true configuration of the ocean basins. When deep soundings were first undertaken, an attempt was made to haul up the whole sounding lead. Consequently a heavy line was necessary and, when any considerable length was out, its weight bore so close a ratio to that of the sinker that in deep water it was impossible to tell when bottom had been reached. Furthermore, the line kept running out endlessly of its own momentum even after the sinker had touched. On the early charts, for instance, some fantastic figures appear for mid-Atlantic soundings which can be attributed to this cause.

The first attempts that can claim even approximate accuracy at depths exceeding 1000-1500 fathoms were made in the United States Navy by using a light line and a heavy weight. It was easy to tell when bottom had been reached by the sharp check in the rate at which the line ran out. The line was then cut, and no attempt was made to retrieve it or the sinker. The depth was ascertained by the simple method of measuring the remainder. The next important advance, made by a midshipman named Brooke, eliminated the obvious drawbacks of the former method. Still using a light line, the weight—a cannon ball with a hole through it—was released when it landed on bottom, and the sounding tube—a metal cylinder which passed through the ball—alone was hauled to the surface. Simple as this seems from the vantage point of today, this scheme of detaching the weight made the difference between accurate and inaccurate soundings in deep water. Piano wire soon replaced hemp, again with an increase in the accuracy of the results and a great reduction in the time

required for sounding, as the frictional effect of the water on rope was thereby eliminated. The machines for handling the wire have been greatly improved since Sir William Thomson's first attempt, so that it became possible to take a sounding in a small fraction of the time formerly required. This method remained in general use until the perfection of echo sounding within the last decade. In the literature perhaps too much stress has been laid on the soundings made by various oceanographic expeditions. An enormous amount has been done in deep water by government vessels, and, of course, all near-shore and shallow-water surveying is a government undertaking. Nor should the cable ships be forgotten. They, likewise, have played an important part in charting the oceans—a fact not generally appreciated—for it was the need for a better knowledge of the ocean bottoms in connection with laying cables that first stimulated systematic deep-water sounding.

RISE OF MODERN TRENDS

By 1900 the broad configuration of the ocean basins had been mapped, and all the major deeps had been discovered and charted. This, plus a very general knowledge of the distribution of the sediments, particularly the pelagic oozes, comprised the chief contributions to geology before the advent of what we shall call the modern period. The other sciences, especially biology, had advanced much further in the same interval. This lag is largely due to the fact that few geologists paid any attention to the sea, except around its margins. They seemed to regard oceanography as lying outside the boundaries of their particular domain and having little to offer. Men whose chief interest lay along other lines were mainly responsible for what geological information there was.

Up to this point the study of oceanography had proceeded more or less along the same lines which the *Challenger* expedition had laid down. The same general problems were attacked in the same general way and from the same point of view. The biological sciences, particularly systematic zoology, had long been the main spring which motivated oceanography as a whole, but even here diminishing returns were beginning to be felt toward the end of the century, as each subsequent expedition merely added data which tended to confirm what was already known. "And", as Dr. H. B. Bigelow (1931, p. 8-9) says,

> "a period of general oceanographic stagnation might then have succeeded to the preceding peak of activity (this did, in fact, happen in America), had there not arisen new schools, centering their attention on the biologic economy of the inhabitants of the ocean as related to their physical-chemical environment, on mathematical analysis of the internal dynamics of the sea water, and on the geologic bearing of submarine topography and sedimentation, rather than on areal surveys of one or another feature of the sea.

"This conscious alteration of viewpoint, from the descriptive to the analytic, is one of two chief factors that gives to oceanography its present tone: the other is the growth of an economic demand that oceanography afford practical assistance to the sea fisheries."

In Europe the Conseil International pour l'Exploration de la Mer was formed as a co-operative effort to handle this latter problem of such vital importance to the nations engaged in the North Sea and neighboring fisheries, and attention was perforce directed to the shallower waters. Interest in the mathematical study of the dynamics of the circulation of the sea centered in the Scandinavian countries. This school developed rapidly until today perhaps more attention is focused on physical and dynamical oceanography than on any other single subdivision of the science.

Lest it be thought that too much space has been devoted up to this point to nongeological matters, it is once again pointed out that oceanography is, of necessity, a co-operative affair, and not to consider the development of the science as a whole is to lose perspective. Interest and impetus generated in one field may be used to advantage in another. Indeed, if this were not the case, submarine geology in its present state would not exist. Although the recent advances in surveying methods, in the application of geophysical techniques, and in sedimentation and stratigraphy have been marked, and in some cases spectacular, the geologist must remember that the main emphasis in oceanographic research is still on physics and the internal dynamics of sea water and on biology.

RECENT ADVANCES IN SUBMARINE GEOLOGY

INTRODUCTION

The student of submarine geology, except in the field of sedimentation, tries to attain the same objectives that are pursued ashore. The difficulties arise in adapting the various land techniques to marine conditions and in handling the necessary gear on shipboard. Whatever the objective, it is subject to the limitations that a ship imposes, and the first thing which an oceanographer must realize, no matter what his field of endeavor, is that it is impossible to work with the same precision that is attainable ashore. This is a perfectly valid objection, but, if it were heeded, no oceanographic work of any kind would ever be undertaken.

MODERN MARINE SURVEYING

The prime requisite for most geological undertakings is a good map; therefore, let us first take up modern developments in charting the ocean bottom. As we have seen, until comparatively recently deep-water soundings were taken with small diameter wire and a sinker, and, although the machines for handling the wire had been improved to a point where

the operation was vastly less time consuming than during the early period when hemp was used, nevertheless, accurate soundings could be obtained only during good weather, and in any event the ship had to be stopped. Modern echo sounding has come into general use only since the World War. Although prior to this date attempts had been made to locate icebergs by this method, its value in the detection of submarines led to more intensive experiments. The term echo sounding is practically self-explanatory. The recording instrument measures the travel time of the sound wave through the water from the ship to the bottom and back again, translated into terms of distance. As the velocity of sound through water varies somewhat with the density, it is necessary to make temperature and salinity observations in the different water masses for accurate soundings. Many types of instruments have been developed, and it is not necessary to go into the details of their construction here. With the earlier models it was necessary to read off each individual sounding, but recently they have been made self-recording. The tremendous advantages of this machine are that the surveying vessel can sound continuously while steaming at full speed, accurately, and in comparative independence of the weather. To quote Captain G. T. Rude (Geophysical Exploration of the Ocean Bottom, 1937, p. 10-11),

"... in fifteen working days in the month of July, 1937, the party on the Coast and Geodetic Survey Ship *Lydonia* recorded 12,489 soundings on the continental slope and covered an area of 1764 square statute miles extending more than 150 miles off shore, all of which was precisely controlled by radio acoustic ranging and taut wire traverses tied in to the shore triangulation net on North American 1927-Datum."

As a contrast he cites the 504 deep-sea soundings made by the *Challenger* and the then remarkable number of 3195 made between 1874 and 1879 by the *Blake*. Similar work is constantly being carried out on the Pacific coast and in the Gulf of Mexico as well as on the Atlantic.

Almost as important as the development of the fathometer is the new method of determining positions accurately at long distances from shore (Geophysical Exploration of the Ocean Bottom, 1937, p. 9-25). Formerly only the inshore waters within sight of the triangulation stations were accurately surveyed. Once out of sight of these fixed marks the position of the surveying ship becomes more and more doubtful as she proceeds off shore, until at some distance from land the positions of individual soundings on the older charts are not much more accurate than an ordinary sextant fix. As an illustration, on all charts prior to 1938 the steep, outer part of the Hudson Gorge makes a pronounced S-curve. The recent surveys have shown that this S-curve is fictitious, and that the head of the Hudson Gorge had been connected with the mouth of a smaller neighbor, and its own mouth had been missed entirely. When vessels were slow

a very generalized representation of the continental shelf and slope was considered sufficient for all practical navigational purposes, but now, when many liners have cruising speeds of over 20 and even 30 knots and all are equipped with echo-sounding apparatus, the Survey decided that more accurate detail of the offshore bottoms would be of considerable assistance to shipping. In thick weather a topographic profile could be constructed by taking continuous soundings, and the ship located by comparison with the topography on the chart. This decision on the part of the Survey was more far reaching than was at first realized, for in carrying out this work the true configurations of the now famous submarine canyons were revealed for the first time, far greater numbers of them were discovered than had hitherto been dreamed of, and a major geological discussion was precipitated which is still far from settled.

To solve this difficulty of accurate positions offshore, the United States Coast and Geodetic Survey developed a method which they call radio acoustic ranging (Geophysical Exploration of the Ocean Bottom, 1937, p. 9-25). Briefly the system is this: Two or more radio stations are equipped with hydrophones, and their positions are determined with reference to the triangulation on shore. The surveying vessel, out of sight of land, steams along her course sounding continuously with her fathometer. When a position is necessary, a small bomb loaded with TNT is dropped overboard, and the time of the explosion is recorded on a tape. The sound waves, travelling through the water, are picked up by the shore stations and radioed back to the ship, and the time of reception is recorded on the same tape. The travel times of the sound waves, after the necessary corrections have been applied, give the distance of the ship from each hydrophone. As the surveying vessel works farther and farther offshore it eventually becomes necessary to move the hydrophones farther seaward as well. Originally they were operated from anchored vessels, but recently buoys, equipped with radio apparatus, have taken their place. Both, of course, are tied in with the shore triangulation stations.

One more device is used in offshore surveying—the taut wire apparatus which was originally developed by the British. It consists of a large drum of fine wire which is used as a steel tape in lengths of over 140 miles. One end is anchored to the bottom, and, as the ship proceeds on her course, the wire is paid out over a sheave which registers the distance run. When a large area is surveyed, this method is used to measure the distances between anchored buoys over the shoreward portions of the regions to be covered, as it can be employed successfully only in relatively shallow water. As the work progresses offshore it is replaced by radio acoustic ranging.

All the maritime nations have charted their own coastal waters, and various naval vessels have done valuable work in the deeper ocean basins. The recently published bathymetric charts of the East Indian seas from soundings taken by the *Snellius* expedition are outstanding examples (1934; 1935). Not only do they clearly depict the morphology of the basins, fore deeps, and fault scarps, but the topography is sufficiently detailed to serve as the basis for general geological discussion by Dr. Ph. H. Kuenen of such fundamental problems as the theories concerning the structure and origin of island arcs and fore deeps, so well exemplified in this interesting region.

Surveying on an equally large scale has been carried out in the South Atlantic by the *Meteor*. As a result Stock and Wüst have been able to draw a greatly improved bathymetric chart of that ocean (*Meteor* Expedition 1935-1939). The true configuration of the southern extension of the Mid-Atlantic ridge has been depicted for the first time, as well as the longitudinal basins on either side of it which are separated from each other by smaller transverse ridges.

The United States Coast and Geodetic Survey deserves great credit and the gratitude of geologists everywhere for the introduction of precise methods into offshore surveying. The production of topographic maps such as the series for the Atlantic continental shelf and slopes, drawn from their soundings by A. C. Veatch and P. A. Smith (1939), under a grant from the Penrose Bequest of The Geological Society of America, the detailed work in some of the California submarine canyons both by the Survey and by the Scripps Institute, and the chart of the submarine countours around Bogoslof Island (Smith, 1937) are but forerunners of a type of work which we may expect in the future to become universal.

TERRESTRIAL MAGNETISM

Magnetic surveys at sea, according to Dr. J. A. Fleming (Vaughan *et al.*, 1937, p. 50-56), were first attempted over 200 years ago on Halley's expedition. From that time until the construction in 1908 of a non-magnetic ship by the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, other surveys of varying accuracy were made, depending on the instruments used and the amount of magnetic disturbance set up by the hulls of the different vessels. The commissioning of the *Carnegie*, however, marks the awakening of a full appreciation of the value of magnetic measurements at sea and a concerted effort to make them as accurate as possible by the optimum equipment and by long cruises devoted exclusively to this aim. Seven cruises totalling nearly 300,000 miles were made before this ship was destroyed by fire in 1929.

Any investigation that holds the possibility of making more complete our knowledge of the earth's structure is worth pursuing for its own sake; furthermore, data accumulated in this field can also be used to advantage in other branches of geophysics, particularly gravimetric studies. This being the case, the need for additional observations at sea are self evident, considering the large portion of the earth's crust that is covered with water, and entirely aside from the practical values of these studies as an aid to navigation at sea and in the air.

Fleming (Vaughan *et al.*, 1937, p. 53) lists a few theoretical investigations which should be continued in the further survey of the oceans:

"Determination of secular-variation of progressive changes of the Earth's magnetic field involving particularly their accelerations . . . ; . . . The study of regions of local disturbance and particularly of those indicated . . . over 'deep-sea' areas . . . ; . . . The determination of additional distribution-data in a few large areas not already covered."

Simultaneously with these investigations work should be continued in the field of terrestrial electricity along the following lines:

"Additional determinations to establish changes in the values of the atmospheric-electric elements with geographic position. . . . More and widely distributed determinations of the diurnal variations in atmospheric electricity . . . Determinations and investigations in the field of earth-currents—a field not yet touched at sea."

Although the Carnegie Institution did not build another ship, the British Admiralty, in view of the importance of these investigations, decided to continue them and ordered the construction of another nonmagnetic vessel, the *Research*, to be placed in commission with equipment similar to that formerly used on the *Carnegie*.

GRAVIMETRIC MEASUREMENTS

Attempts to measure gravity at sea by static methods have never proved particularly accurate although many different instruments of this type have been devised. The pendulum has always been the standard instrument on land but, because the difficulties of using it on board surface ships seemed insurmountable, it was disregarded by the earlier workers. In 1923, the Gravity Survey of Holland began to consider the possibilities of using a submarine for this work, and, after preliminary tests, the first really accurate measurements were made, on board a vessel of this type, by Dr. F. A. Vening Meinesz, on a cruise to the Dutch East Indies. Two pendulums were employed instead of one to eliminate the effects of horizontal acceleration. So successful was this cruise that, following the lead of the Dutch, similar expeditions were sent out by other countries. Since 1928 the United States Navy on three separate occasions, in co-operation with Princeton University, has dispatched a submarine for surveys in the West Indies, and the French, Italians, Russians, and Japanese one or more

each to the Mediterranean, Black Sea, and the Far East. The Netherlands, in the meantime, has completed seven additional surveys and is about to send out an eighth. The original apparatus has, of course, been considerably modified and refined since the first model was constructed, but the Meinesz method has been followed in all this work.

As in the case of terrestrial magnetism, not only is it desirable to extend the measurement of gravity to the oceans so that the areal survey of the earth may be as extensive as possible, but in this particular case fundamental data can be gathered at sea that cannot be obtained on land. The discovery of the large negative anomalies in the vicinity of island arcs and fore deeps has greatly influenced our ideas on the processes involved in mountain building and gives another clue as to what may have happened in depth during deformation. Solving the problem of measuring gravity at sea may be ranked as one of the major contributions of geophysics to geology in recent years (Vening Meinesz, 1932; 1934).

SEISMIC TECHNIQUE

The importance of seismic techniques as an aid to structural geology has long been recognized, but the practical difficulties which stood in the way of the adaptation of this well-known procedure to marine conditions long delayed its use at sea. It is the most recent of the three geophysical methods to be applied to oceanic problems. The first experiments were carried out in the shallow water of our east coast continental shelf by Dr. Maurice Ewing (1937) 5 years ago. The technique for shallow water can be regarded as nearly perfected, while that for deep water is still in the experimental stage. A new development in the technique for deep water work is the use of floats filled with an oil of low density, for bringing the instruments to the surface, thereby dispensing with a long wire rope which has many disadvantages. The first plans, as described by Ewing (1938), have since been greatly modified, though the principle remains the same.

A profile consisting of four sea stations has been run from Cape Henry, Virginia, across the shelf to the continental margin, and while, of course, one profile is far from being a complete picture, it has demonstrated that the method is a usable one and that a new tool has been acquired. A thickness of the order of 12,000 feet of unconsolidated and semiconsolidated sediments is found at the continental margin over rocks which registered much higher velocities. This presumably represents the thickened seaward extension of the Coastal Plain monocline lying above the relatively flat basement complex, which itself has a seaward dip. The same relationships which have been observed in the subaerial portion of the Coastal Plain are apparently continued beneath the sea. The east

coast shelf, with its relatively simple structure and the presence of numerous, deep artesian wells close to the shore line, is a particularly favorable place for the development of this new technique.

Recently Drs. E. C. Bullard and T. E. Gaskell have used the same method in the approaches to the English Channel out to a point 175 miles WSW. of the Lizard. At the station nearest shore it is thought that an extension of the Triassic is picked up. Farther out unconsolidated sediments were encountered over an igneous basement, but they are relatively thin in comparison with the same type of deposit found off the east coast of the United States.

It is, at present, impossible to predict how far offshore the work can be carried and still retain its significance from a structural point of view, because with increasing distance from the known stratigraphic column, which must be constantly used as a check, the results are more uncertain. This will be even more of a limiting factor in regions where the structure is complicated. Deep water enormously increased the difficulties. This of course is true of any operation carried out on shipboard. However, even though it will never be possible to work at sea with the same precision that can be attained ashore, or to make as close a network of stations, or get in as many shot points, this should be no deterrent to future activity in this particular field, for the same criticism can be leveled at any kind of oceanographic endeavor.

BOTTOM SAMPLING

In the beginning, as we have seen, sampling was merely an adjunct of sounding. A sample was taken merely to inform the navigator, by notations placed on the printed chart, over what general type of bottom he was sailing. For this purpose a small bit of sediment plugged in the sounding tube or a smear stuck to the grease on the end of the lead was sufficient. Later, scraper dredges were developed by the biologists, and various kinds of scoops and bucket dredges, capable of taking measured portions of the bottom, were designed for ecological studies. However, these men were mainly interested in obtaining samples for the animals which they contained, and the sediment itself was broadly classified as sand or mud and usually discarded.

The coring tube can be considered as a sampler primarily for geological purposes. Until the invention of the Piggot gun, those used in anything but the shallowest water were merely weighted tubes, which penetrated the bottom by their own kinetic energy. They attained varying degrees of success, depending on their weight and the speed at which they could be dropped. Some had a thin, inner tube of glass or metal which could

be slipped out, thus giving the core a permanent container. The length of such cores rarely exceeded 3 or 4 feet, though recently Dr. F. P. Shepard reported taking one of 11 feet.

Coring has played a prominent part in the work of two recent expeditions; the *Meteor* in her traverses across the South Atlantic has taken numerous cores with a modified Ekman type of sampler, and an important series of papers on the sediments and their faunas by Pratje, Correns, and G. and W. Schott has resulted (*Meteor* Expeditions, 1935-1939). Besides showing the areal distribution of the different types of material, the tube penetrated deeper layers in which evidence of climatic changes are recorded. The *Snellius,* in the Dutch East Indies, also took many cores, particularly in and around the deeps and on the slopes of submarine volcanoes. These have been discussed by Kuenen (*Snellius* Expedition, 1935) in connection with the question of the sliding of sediment down the sides of the deeps as a process which might tend eventually to fill up these downwarps, and also with regard to the structures which submarine landslides might be expected to produce.

The Piggot gun has been fully described by its inventor, and the details of its construction need not be discussed here (Piggot, 1936). Support for the original design and experimentation was furnished by a grant from the Penrose Bequest of The Geological Society of America. The driving force for the tube, or bit, is produced by a powder charge, contained in a water-tight cartridge, which is detonated when the instrument hits the bottom. More uniform performance has been secured with this coring tube in deep water than with any other yet devised, and cores up to 10 feet in length are frequently taken, although occasionally greater lengths have been attained by tubes which are dropped at high velocity. The extra 6 or 7 feet of core obtained by these newer instruments may not seem to be of much significance as compared to the probable total thickness of the deposit, but it must be remembered that the rate of deposition decreases as one goes beyond the continental slopes into the ocean basins. Accordingly, 10 feet of sediment may represent a considerable interval of time. Indeed, in a series of cores taken by Piggot across the Atlantic basin, and worked up by the United States Geological Survey, four warm and four cold alterations of climate are represented (Geophysical Investigations, Bradley *et al.*, p. 41-46).

Using this same instrument numerous cores have been taken by the *Atlantis* in and around the east coast submarine canyons, along the continental slope, and for some distance out into the Atlantic basin. In these, one or more climatic cycles are usually found. The present-day warm-

water fauna from the tops of the cores occurs in a green silt which is being deposited under modern marine conditions. The cold-water fauna from the bottom sections is found in a compact, vari-colored clay. Such fine-grained, terrigenous material is not being deposited on the surface of the present-day bottom in this area, on the shelf, slope, or even in the westerly part of the Atlantic basin, as practically all river-borne sediment is now effectively trapped in the bays and estuaries which today border the entire eastern seaboard. The clay in question evidently dates from the last glacial stage of the Wisconsin when, because of the lowered sea level, the rivers were able to cross the shelf and dump their loads directly on the steep continental slope.

The possibilities, therefore, of being able to trace the history of Pleistocene sedimentation in the Atlantic basin and on the continental slope by the continued use of the coring tube are very good. It is even possible that from this source some light may be thrown on the far from settled problem of the origin of submarine canyons. This investigation is already under way at the Woods Hole Oceanographic Institution, and similar work is in progress at the Scripps Institution of Oceanography at La Jolla. At the latter institution an extensive program for submarine geology is being carried out under the direction of Dr. F. P. Shepard, which is, in part, financed by a grant from the Penrose Bequest of The Geological Society of America.

Cores have one limitation which is only just beginning to be recognized. The deeper the tube penetrates the sediment the greater becomes the friction on the inside walls of the tube. Dr. M. Juul Hvorslev of the Harvard Engineering School has recently completed extensive sampling experiments for the Committee on Sampling and Testing, American Society of Civil Engineers, in varved clays with different types of coring tubes. He finds (personal communication)

"that the layers in the upper parts of the cores are often subjected to an increase in thickness due to plastic flow of additional soil into the tube caused by the pressure of the cutting edge. With increasing depth of penetration, and thereby increasing friction between the sample and the tube, the general load on the soil becomes so great that it now becomes squeezed out from under the sampler and the thickness of any given layer is thereby reduced. Finally at a certain critical depth, internal wall friction becomes so great that no more soil can enter, and the core and tube are driven as a solid pile, pushing a cone of sediment ahead of them. There is, therefore, for each particular type of sampler, and for each type of soil, a maximum length of sample that can be obtained in a single drive. When the soil consists of alternating layers of firm and soft material a further complication, originally observed by Pratje, arises in that the soft layers may be squeezed out partly or completely while the firm layers still enter the tube without any change in thickness."

This behavior of the material introduces a serious factor of error into all attempts to determine rates of sedimentation from linear measurements.

SHALLOW WATER SEDIMENTS

Like organisms, sediments are the resultants of the long sequence of factors to which they have been exposed: current action, wave-generated and otherwise, distance from shore and depth of water, the type of material supplied and its availability, plus their combined effect in the past. These environmental forces have acted on the sediments at their source, during the period of transportation, and at their place of deposition. Many inferences have been drawn in regard to the conditions of marine deposition from the study of sedimentary rocks, but insofar as present-day marine sediments are concerned very few observational data have been accumulated. Of the sediments in the geologic column those laid down in the neritic zone bulk the largest, but our knowledge of them is still very elementary. The earlier oceanographers were, as we have seen, more interested in the deposits of the deep sea and they added but little information concerning those sediments which to the geologist are the most important. Chiefly by increasing our knowledge of present-day marine sediments and the environments under which they are being deposited will we be able to reconstruct with any degree of certainty the conditions which governed the formation of ancient sediments. With this purpose in view, detailed regional studies are now being carried out off the Atlantic and Pacific coasts, by the Woods Hole and Scripps Institutions, based on traverses of closely spaced surface samples as well as long cores. In addition, some approach has been made to an understanding of the factors controlling the transportation and deposition of sediments by means of traps placed on the bottom, although this work is still in its early stages.

Additional regional studies have been carried out in the Baltic and neighboring waters by the Thalassological Institute at Helsinki and by the marine laboratory of the University of Kiel; these studies have added much to our knowledge of the conditions of sedimentation found in inland seas. Princeton University has sponsored expeditions to the Bahamas for the investigation of shallow-water, calcareous sediments, a relatively unexplored field. It is hoped that data obtained from studies of this type, to cite but a few examples, will help solve some of the problems of the stratigrapher and lead to a better interpretation and understanding of the environments which produced the different sedimentary rocks.

SUBMARINE CANYONS AND ROCK DREDGING

Within the last few years the submarine canyon problem has provoked so much discussion that the subject has become familiar to all geologists. Although their existence has been known since J. D. Dana's day they had attracted but little attention until the U. S. Coast and Geodetic Survey

completed the first surveys of Georges Bank by radio acoustic ranging. For the first time an adequate picture of their true configuration was available, and Dr. F. P. Shepard (1933; 1934) was quick to grasp the significance of the new evidence. As more of these gorges were discovered and particularly as the continental slope between the major valleys was shown to be deeply scoured and channeled, geologists realized that they were faced with a problem, world-wide in its scope, for which they had no ready explanation. The multiplicity of the theories that have been put forward is an index of the general perplexity. Some consider that the erosion is due to stream cutting and would alter the relationships of land and sea to a hitherto undreamt of extent (Veatch and Smith, 1939); another conceives of a great lowering of sea level by postulating a vastly thickened and extended Pleistocene ice cap (Shepard, 1936); still others consider that the erosion took place beneath the sea. One hypothesis calls for turbidity currents made heavy by their load of mud acquired from the continental shelf by wave action during the lowered sea level of the Pleistocene. These currents ran down the slope and scoured it as they sought the depths of the ocean, as well as "triggering off" mud slides by the friction of their passage (Daly, 1936). The latest hypothesis in the case of the east coast of the United States invokes artesian springs flowing out from the Coastal Plain formations along the continental slope, possibly at a time when this wedge of sediments had a greater westward extent than it has today, and by their long-continued action producing the present topography largely by solution. Before introducing his new theory Johnson (1939) gives an excellent account of the whole canyon problem to date.[1]

Whatever their origin these submerged canyons offer the only available opportunities for getting at the older formations beneath the mantle of Recent veneer, for in places their walls stand as cliffs, steeper than the angle of repose of unconsolidated sediment. The fossiliferous fragments broken from the outcropping ledges indicate that these valleys are comparatively young. This adds to the complexity of the problem because we cannot retreat into the security of the distant past when called upon for an explanation of their origin. Heavy iron scraper dredges have been successfully employed, in comparatively deep water, both by Woods Hole and Scripps, off the east and west coasts, for obtaining samples from these outcrops. Where the beds are nearly horizontal it is even possible to work out roughly the stratigraphic succession. This serves the double purpose of not only giving some information as to the rocks constituting the conti-

[1] Since the manuscript has been completed yet another theory has been added to the list. Bucher (1940) considers that the erosive effect of tsunamis spending their energy against the continental slope may be the most important single factor in producing this maturely dissected submarine topography.

nental shelves but also of fixing at least the maximum age of the canyons. On the east coast the formations are all sedimentary, ranging from Upper Cretaceous through the late Pliocene. In texture the different beds vary from indurated sandstones to friable greensands and compacted silts and clays (Stetson, *et al.*, 1936). Cores taken from the bottom of the canyons show a clay, with Arctic Foraminifera, presumably deposited during the last stage of the Wisconsin. The time of canyon excavation can thus be bracketed with fair exactness, and further work will doubtless narrow this span. Mollusks and echinoderms have proved useful in some cases as guide fossils, but Foraminifera have been by far the most valuable. Although the shelf is the submerged extension of the Coastal Plain, the fauna of the sediments at the continental margin differs from that of the emerged portion, and the formations evidently belong to different facies. In some cases there is a curious parallelism with the warm-water fauna of the Mississippi Embayment. The walls of the west coast canyons likewise consist, for the most part, of sedimentary formations, the youngest of which are Pliocene, although in the upper part of Monterey Canyon Shepard has reported granite. Any theory which is put forward to explain the much disputed question of origin of these extraordinary topographic features must take into account the data which this dredging has afforded —namely, their age and the type of rock into which they are cut. Similar work in the canyons of other continents is much to be desired, in order that all possible information may be brought to bear on this perplexing and still unsolved problem.

PRESENT STATUS AND FUTURE DEVELOPMENT OF SUBMARINE GEOLOGY

As a result of a newly awakened interest, stimulated by the introduction of new techniques, the geological branch of the science is, at present, in a position to make a rapid advance. The foreword to the reports of the *Snellius* Expedition (1937, p. vii) reflects this change of attitude which has taken place both here and abroad.

"While in the Siboga-expedition of 1900, biology stood in the foreground, physical oceanography came only in second place and geology was not included in the programme at all, in the Snellius-expedition the parts were reversed and moreover a prominent place was given to geology."

The application of the geophysical methods has placed within our grasp the means of dispelling much of our ignorance concerning the suboceanic lithosphere, a subject of primary importance to our thinking concerning the structure of the earth. The procedure for measuring terrestrial magnetism and gravity can be regarded as perfected, while that for securing seismological data is rapidly approaching that stage.

The recent advances in offshore surveying methods have so far been applied only to charting comparatively small areas of the ocean floor, but these preliminary results, if they may be so called, have been sufficiently startling to unsettle, in many minds, deep-rooted ideas concerning the relative stability of land and sea, and possibly even the permanency of the ocean basins. For others they have stimulated thought concerning submarine currents and rivers of liquid mud of a type which had never before been considered among the processes of erosion. The study of submarine morphology has thus taken on a new significance.

In the field of sedimentation the emphasis is shifting from a purely areal study of a region to investigations of the sediments in relation to the marine environments which have produced them. The forces governing transportation and deposition are all too imperfectly known, and a clear understanding of conditions of sedimentation in the sea today will go far toward helping the stratigrapher in the interpretation of sedimentary rocks on land. Modern methods of mechanical analysis, largely developed in connection with studies in soil mechanics and foundation engineering, and the statistical treatment of data have been of great assistance in this work. The ability to take long cores is playing an increasingly important part in the study of sediments, and it is possible in many instances to penetrate the mantle of present-day deposition and reach the older formations. It is hoped that in this way at least something of the Pleistocene history of the ocean basins may be unraveled. When long cores have been obtained from the red clay of the Pacific, where the rate of deposition is extremely slow, it is expected that valuable data will be obtained on the rate of decay of radioactive minerals, which are exceedingly abundant in these clays.

Little enough is known of the clastic sediments—black shales, for instance—, but even less is known about the origin of limestone and its corollary, dolomite. Chemistry in relation to marine sediments, both organic and inorganic, and its connection with the processes of diagenesis is a field which has scarcely been scratched. Even the composition of the water contained in the bottom sediments and the part it plays is an unknown quantity. Along these lines the possibilities for future development are practically limitless.

No longer does oceanography have to depend on the outfitting of special expeditions for its continued advancement. As a science it has become firmly established, and the study of the sea in all its phases is now carried out both here and abroad. Not only are numerous laboratories devoted exclusively to this purpose, but many government departments have also made it an integral part of their programs. Using this country as an

illustration, the Coast and Geodetic Survey has engaged in charting operations which have proved particularly significant in the field of submarine morphology. The Navy has furnished submarines on several occasions for the measurement of gravity at sea, and the Hydrographic Office is constantly accumulating and publishing deep-sea soundings. The Coast Guard has incorporated the study of the internal dynamics of sea water as part of its work on the ice patrol off the Grand Banks of Newfoundland. The Bureau of Fisheries investigates for the most part ecologic problems which concern the various inhabitants of the ocean but has also taken much hydrographic data. Similar work is being carried out by the governments of all the important maritime nations.

If the greater part of the initiative and impetus for the development of the biological and physical oceanography has been furnished by European countries, America may lay claim to this role in the field of submarine geology. The support which has been, and continues to be, furnished by institutions, learned societies, and government agencies in this country in the form of money, ships, and equipment is a measure of the importance of the problems and of the success which has been achieved. However, after the original impetus has been given, international co-operation is essential if the study is to reach its fullest development. There is every indication that such will continue.

To attempt a list of institutions and bureaus engaged in oceanographic work or to make a complete catalogue of present activity in submarine geology is not the purpose of this chapter. The student desiring such information should turn to a recent publication of the National Academy of Sciences edited by Dr. T. Wayland Vaughan (1937) where these data have been fully compiled, and which also gives a bibliography of the serials which are published by the various institutions. The bibliography appended here is only intended to give a person unacquainted with the subject a working knowledge of the literature and to provide a starting point. The purpose of a short sketch of this sort is to trace the rise and development of present-day trends and lines of endeavor in submarine geology and to present a summary of progress, as seen against the background of oceanography as a whole, so that the general perspective does not become distorted.

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MELANOSIS IN THE COMMON COD, GADUS CALLARIAS L., ASSOCIATED WITH TREMATODE INFECTION [1]

SIDNEY C. T. HSIAO [2]

(From the Museum of Comparative Zoölogy, Harvard University, and the Woods Hole Oceanographic Institution, Woods Hole, Mass.)

A codfish displaying an unusual degree of melanosis is described in this paper. The fish was caught one mile north of Race Point, Provincetown, in March, 1940, by Mr. J. W. Lowes, who sent it to the Museum of Comparative Zoölogy. Mr. William C. Schroeder asked the writer to make a histological study of the tegumentary system of the specimen in a search for a possible clue to the cause of its melanosis.

Method

Samples of skin of one-half to one centimeter square were taken from different parts of the head, trunk and fins. The regions employed are indicated by letters and numbers shown in Fig. 1. Each sample was dehydrated, cleared and mounted in balsam. With a calibrated ocular micrometer ruled into squares, 3 to 5 separate square millimeters from

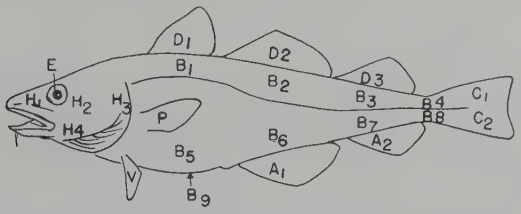

Fig. 1. Diagram of left side of cod showing regions from which skin samples are removed for comparative study. *A*, anal fin; *B*, body or trunk; *C*, caudal fin; *D*, dorsal fin; *E*, eye; *H*, head; *P*, pectoral fin; and *V*, ventral fin.

each piece of skin were measured under a binocular microscope, using reflected light, and the number of pigment cells per square millimeter determined and recorded from each region.

Small pieces of skin from the first dorsal fin (region *D 1*), the trunk, directly ventral to the first dorsal fin (region *B 1*), and the cornea (re-

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gion *E*) were sectioned and stained with Heidenhain's "azan" stain which gives a blue color to the connective tissue, reddish yellow to the muscles, carmine to the cyst wall formed by the host tissue, blue to the cyst wall secreted by parasites and blue and carmine to the parasites themselves.

For comparison a normal cod was treated in the same way.

The trunk muscles, gills, oesophagus, heart and peritoneum were examined for parasites. As the fish had been eviscerated, only remnants of the cardiac portion of the stomach and liver were examined. The cysts were isolated, stained, and mounted and some of them sectioned and stained.

Observations

Superficial examination of the whole fish and microscopic study of sections of its skin show that general cutaneous melanosis in this fish is associated with parasitic infection which attacks the whole tegumentary

Fig. 2. *A*. Normal cod. *B*. Dark cod described in this paper.

system and the gill filaments. No parasitic cysts were found in the somatic muscles, the peritoneum, the heart, the oesophagus, the remnants of the liver and the cardiac end of the stomach which happened to be left in the fish after its evisceration. These uninfected regions exhibit no melanosis when compared with the corresponding regions in the normal cod.

In general appearance this fish is strikingly different from an ordinary cod in the presence of so many melanophores in the corneae and in the skin over the fins and the dorsal half of the body that these parts are actually black. The contrast in color between this and normal cod is shown in *A* and *B* of Fig. 2, which are printed from one photographic negative and hence are of identical exposure. Instead of being smooth and shiny, the skin is warty and rough. The tiny excrescences which produce the roughness are covered with more melanophores than the surrounding tissues. Parasitic cysts appear as white specks among the melanophores. Inside the cysts different stages of the metacercaria of a heterophyid trematode are seen.

The cysts and melanophores are so abundant in the cornea that the fish is blind and the eye scarcely distinguishable from the rest of the head. The melanophores on the body above the lateral line and on the dorsal and caudal fins are so numerous that they form a continuous sheet, making it impossible to ascertain their number per unit area of skin. In the less densely pigmented regions the dark cod has, on the whole, about six times as many melanophores per square millimeter on the head and six to nine times as many on the paired and anal fins as has a normal cod. Table I shows the number of pigment cells per square mm. for each of the 23 corresponding samples of skin from the dark and normal cod. The last two columns show that the melanophores of the dark cod are smaller than those of the normal fish. In the dark fish the melanophores are more uniform in size. In Fig. 3, *A* and *B*, two equal pieces of skin from the pectoral fin of a normal cod and this dark cod are compared. The normal cod has only one-sixth as many pigment cells as the dark individual.

Parasitic cysts are present in the tegumentary system from the tip of the snout to the surface of the caudal fin, including both corneae. When examined under a dissection microscope, they appear as small white dots among thick masses of melanophores—the tips of the cysts being free from pigment cells. From Fig. 3, *C*, it will be seen that the rugose appearance of the skin is produced by a mass of parasitic cysts under the epidermis which is thrown into folds. These cysts occur both above and below each scale, which, when pulled off from the body, always has a mass of cysts firmly attached to its two surfaces. The connective tissues are hypertrophied so that the skin is more than three times as thick as the normal skin from a corresponding part of the body (Fig. 3, *D*). The cornea is also infested. In Fig. 3, *F*, which is a photomicrograph of a 4 μ thick section of a piece of cornea, 10 trematode cysts can be seen from a field 1.86 mm. long and 0.66 mm. wide. This

cornea is more than twice as thick as a normal one a id has melanophores throughout its whole thickness.

TABLE I

Comparison of melanophores between dark and normal cod

Body region	Number of melanophores		Ratio of melanophores: Dark / Normal	Size of melanophores in mm.	
	Normal	Dark		Normal	Dark
Head:					
H 1	25	121	5	0.15–0.2	0.1
H 2	10	72	7	0.3	0.1–0.2
H 3	12	72	6	0.3	0.15
H 4	9	63	7	0.3	0.25
Trunk:					
B 1	46	Too		0.2	0.05–0.1
B 2	51	numerous		0.2	0.05–0.1
B 3	55			0.2	0.05–0.1
B 4	82			0.1	0.1–0.15
B 5	7			0.3–0.4	0.1–0.15
B 6	7			0.3	0.15–0.2
B 7	17			0.2	0.2–0.25
B 8	14			0.4	0.15–0.2
B 9	1	19	19	Contracted	0.2–0.3
Dorsal fin:					
D 1	48	Too		0.15–0.2	0.1
D 2	39	numerous		0.2	0.1
D 3	55			0.15–0.2	0.1–0.2
Anal fin:					
A 1	5	40	8	Contracted	0.2–0.3
A 2	5	51	10	0.2–0.4	0.2
Caudal fin:					
C 1	87	Too		0.1	0.1
C 2	45	numerous		0.15–0.2	0.1
Pectoral fin:					
P 1	5	46	9	0.4	0.1–0.15
Ventral fin:					
V 1	6	37	6	0.2–0.25	0.2
Eye:					
E 1	0	66		0	0.2

The parasitic cysts are thick-walled, ovoid in outline and white to the naked eye. The majority of the cysts measure 0.33–0.38 mm. along one principal diameter and 0.24–0.28 mm. along the other. The cap-

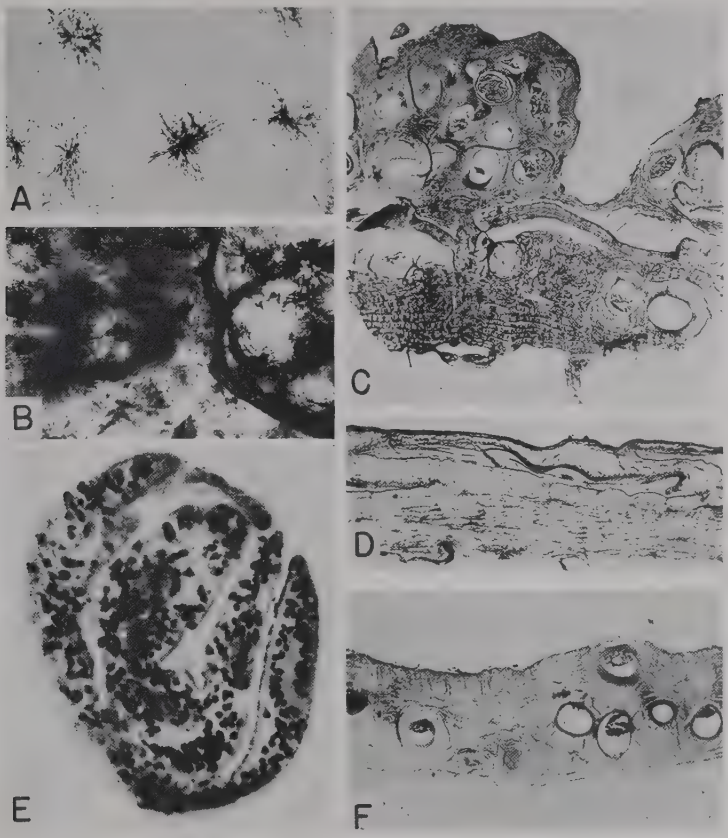

FIG. 3. Photomicrographs of preparations from cod skin.

A. Skin from the pectoral fin (same region as in *B*) of a normal cod.

B. Skin from pectoral region (*P* 1) unstained, showing part of the outline of two cysts and melanophores.

C. Section of a piece of melanotic cod skin from region *B* 1 (below the first dorsal and above the lateral line), showing the wavy epidermis and clusters of cysts. Section of one scale is shown in this figure. Three cysts are seen under the scale, while above it there is a large number of cysts.

D. Skin of normal cod from the same region and under the same magnification as in *C* above, showing one scale in section and part of two others and the smoother epidermis and less connective tissue.

E. Section of a metacercaria.

F. Section of the cornea showing cysts and pigmentation.

sules secreted by the parasites to enclose themselves measure 0.21 mm. by 0.14 mm. in the two principal diameters. The cyst walls are very resistant to mechanical injuries and are transparent in unstained skin cleared in xylene and mounted *in toto* in balsam. The cyst wall secreted by the host stains bright carmine with Heidenhain's "azan" stain and is laid down in concentric layers. It measures 0.028–0.07 mm. in thickness. The cyst wall secreted by the parasite, on the other hand, is only about 0.007 mm. thick and stains blue. In the gill filaments many smaller cysts are seen. This difference in size is due to the thinness of the host wall, for the smaller cysts contain parasites which, when measured along the parasite wall, are of the same size as those enclosed in the larger cysts of the gill filaments or the skin of the trunk. The host wall about the parasite increases in thickness, with more concentric layers, as the external size of the cyst increases. There is comparatively very little pigmentation about the cysts in the gill. All the melanophores present in the gill are arranged about the cysts with thick host walls. As the host walls are laid down about the parasites in concentric layers centrifugally and as the melanophores are associated with the more peripheral layers, it is probable that these pigment cells appear some time after the infection occurs.

The cyst contains the coiled body of the metacercaria of a trematode whose suckers can be distinguished through the transparent cyst walls. In stained sections (Fig. 3, *E*) the suckers and the spines on the posterior part of the body wall of the parasite can be seen easily. But as the metacercariae are still young, it is not possible to work out the structures of the reproductive system of our material.

From the absence of the parasitic cysts inside the body of the fish except in the tegumentary system and the gills, it may be inferred that the trematode larvae infected the cod by boring from the outside. The presence of very thin-walled parasitic cysts in the gill filaments indicates that these were the latest site of infection.

Compared with other infected fishes, this cod shows an extraordinarily heavy infection. Not only is the whole tegumentary system completely infested with parasites, but the parasitic cysts are gathered in groups several layers thick under the epidermis. According to Dr. Stunkard (verbal communication), a cunner kept in a laboratory aquarium for six weeks with 50 infected snails giving off thousands of trematode larvae does not get nearly so heavily infected. It is the more surprising when we consider that although in the ocean the cod was able to move about, it nevertheless contracted such an enormous number of parasites.

Discussion

Many cases of melanosis associated with parasitism have been observed among freshwater fishes. There are also a few records of melanosis in marine fishes parasitized by trematode larvae. In 1884 Ryder reported his observations on the darkening of the skin in parasitized cunners from Woods Hole and Cape Breton, N. S. He thought that these cysts were formed by the cercariae of some trematode and that the pigment cells about the site of infection were either formed *de novo* or gathered there by migration. Linton (1900) observed parasitic cysts on the skin of cunners in 1889, and in 1901 he reported similar infections on tautog, winter flounder, tom cod and eel and "less so on others." In 1915 he recognized the similarity between these encysted forms and the trematode *Tocotrema lingua* (Creplin). The presence of this species on the gills of sea raven and on the skin of cunners from Passamaquoddy Bay was reported by Cooper (1915). Stunkard worked out experimentally (1930) the life history of this trematode and identified it as *Cryptocotyle lingua* (Creplin), belonging to the family Heterophyidae—*Tocotrema* being long suppressed as a synonym of *Cryptocotyle*. Smith (1935) described a hyperplastic epidermal disease in two winter flounders associated with a trematode infection which was probably due to *Cryptocotyle lingua*. All these observations were probably concerned with the same species. A second species was reported by Gamble and Drew (1911) from Plymouth. A whiting infected by trematode larvae showed abnormal pigmentation in the form of black specks scattered over its pigmented areas and over the conjunctiva. They suggested that the trematode was a species of *Holostomum*, probably *H. cuticola*. No melanosis due to parasitism in the cod has been reported. In the cod described here the heaviness of infection and the intensive reaction of the host in the hypertrophy of the skin and the development of excessive melanophores are very remarkable.

Smith's experiments (1931, 1932) on the evoking of melanophores through mechanical injury and the eruption of corial melanophores and general cutaneous melanosis strongly suggest that these reactions are related to repair and defense of the tissues. The general eruption of melanophores in this cod, whose tegumentary system was completely infected by trematode metacercariae, is probably a defensive reaction against the parasite. There are different views on the question whether the melanophores in a parasitized fish migrate to the site of infection or are formed *de novo*. In this particular cod the number of melanophores is so much in excess of that found in an ordinary cod and they

so completely cover the whole body that migration of melanophores cannot account for them. They must have developed anew.

The development of the metacercariae is not advanced enough to allow an exact identification of the parasite. However, the mode of reaction of the host and the structures of the parasite, as far as they can be determined, appear very similar to what Linton described for *Cryptocotyle lingua,* which is found to infect a variety of fishes such as cunner, tautog, tom cod, eel, sea raven, winter flounder, etc. They suggest that this cod is parasitized by a species related to *Cryptocotyle.*

Summary

A very melanotic codfish is described which proved to be heavily infested with metacercariae of a heterophyid trematode. The number of parasites and the intensive reaction of the host in the development of melanophores and hypertrophy of the dermis are greater than any recorded for parasitized fish. The parasite may be a form related to *Cryptocotyle.*

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U. S. TREASURY DEPARTMENT

COAST GUARD

OCEANOGRAPHY

EXCERPT FROM

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ICE PATROL SERVICE
IN THE NORTH ATLANTIC OCEAN

Season of ~~1936~~ 1929

UNITED STATES
GOVERNMENT PRINTING OFFICE
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OCEANOGRAPHIC CONDITIONS IN THE GRAND BANKS REGION AND THE LABRADOR SEA IN 1939

By Floyd M. Soule [1]

The *General Greene* departed from Woods Hole on March 21' proceeding to St. John's, Newfoundland, where she arrived on March 25. After fuel and supplies had been taken on departure was taken from St. John's on March 29 for the purpose of making a current survey of the Grand Banks region. Few bergs had been reported but as a considerable quantity of field ice had been reported between the northeastern edge of the Banks and Flemish Cap with patches extending as far south as the Tail of the Banks, it seemed probable that bergs caught in the field ice would soon be freed in positions favorable to their southward travel toward the steamer lanes via the Labrador Current which seemed to be flowing with considerable vigor. It was therefore planned to begin the survey at the northern end as near the field ice as possible and work southward. The first section was not expected to be possible of occupation on account of field ice, but contrary to expectations this region was free of ice and the work of collection of data was begun at station 2848 on March 30. At the first five stations temperature conditions were severe enough to freeze the water in the Nansen water bottles as they came on deck and the bottles had to be taken below into the laboratory to thaw them out and get the water samples. The unprotected thermometers (whose outer cases are filled with water) had to receive similar treatment. This resulted in much additional labor and some delay. Worse than this there was some uncertainty that the salinities determined from the samples which had been frozen and thawed out truly represented the salinity distribution in situ. Ultimate results indicated, however, that the validity of the current map was unaffected.

No major interruptions occured and the work of collection of data was completed at station 2901 on April 8, a total of 54 stations having been occupied. The resulting current map was ready for delivery 12½ hours after the occupation of the last station but the patrol cutter *Champlain* could not be reached until about 2 hours later. The map was then delivered aboard the *Champlain* on the morning of April 9 and the *General Greene* proceeded to St. John's where she

[1] Contribution No. 256 of the Woods Hole Oceanographic Institution.

arrived on April 11 having been delayed by several hours of force 8 wind.

Departure was taken from St. John's on April 22 to make a second current survey. The bergs and growlers which had been reported between April 15 and April 20 north of latitude 44° N., and east of longitude 46° W., indicated the desirability of extending this second survey northward to the latitude of Flemish Cap. The presence of field ice between the Grand Banks and Flemish Cap and between latitudes 46° and 47° N., however, made this out of the question with a ship as ice-vulnerable as the *General Greene*. Furthermore the time which would have been required would have meant that these northern sections could have been made only at the expense of eliminating the sections near the Tail of the Banks and in view of the results of the first survey it was considered that the vicinity of the Tail of the Banks would be an area of considerable importance in regard to menacing ice during the month to follow. It was therefore decided to survey the same general area covered by the first map. Another consideration entering into this decision was that the significance of the northeastern berg reports was mitigated by the probability that these bergs had been caught in field ice which had been blown southeastward and ultimately had been freed in water returning northeastward.

It was further decided to begin the survey at the northern end and work southward. This was a fortunate decision as the northern part of the area mapped was later invaded by field ice which would have made the occupation of the northern section impossible had the direction of progress of the survey been reversed. The work of collection was begun at station 2902 located at 46°23′ N., 48°48′ W., on April 23. Aside from a short detour around field ice on the northern section the work progressed without notable interruption and station work was completed at station 2953 at 42°01′ N., 51°20′ W., on May 2, a total of 52 stations having been occupied. The resulting current map was then constructed and delivered aboard the *Champlain* 12 hours after the last station had been completed. The *General Greene* then returned to St. John's, arriving there on May 4.

On May 20 the *General Greene* departed from St. John's to make a third current survey. It had been planned that during this survey a smaller area than usual would be mapped once and then resurveyed as soon as possible in an effort to learn something of the manner in which the current pattern changes from one survey to the next. The region best suited for such a double survey would be the region with which we are already the most familiar, which in this case is the area immediately eastward of the Grand Banks. However, because of the menace of the southernmost ice to the United States-European steamer lanes, this more ideally located area was discarded

in favor of the region south and southeast of the Tail of the Grand Banks.

Accordingly the work of collection of data was begun at station 2954, located at 42°00′ N., 51°00′ W., on May 21 and progressed from west toward northeast. The first part of the survey was completed without incident at station 2978, located at 42°24′ N., 45°51′ W., on May 27. The current map resulting from these observations was completed 11½ hours later and was delivered aboard the *Champlain* the morning of May 28. The survey could not be repeated because ice and current conditions required that the survey be extended southward instead. Plans were changed accordingly and additional stations were occupied in a strip along the southern and southwestern border of the area originally mapped. Station work was completed at station 2993 located at 40°25′ N., 51°30′ W., on June 1, a total of 40 stations having been occupied.

From the stations occupied during the second part of the survey a supplemental map was drawn. This was completed 6½ hours after the last station had been completed and was delivered to the *Champlain* on June 2. The *General Greene* then proceeded to St. John's where she arrived on June 4.

Departure was taken from St. John's on June 19 for the purpose of making a fourth current survey. This survey extended from about latitude 46° N., to about latitude 41° N. The work of collection was begun at station 2994, located at 46°23′ N., 48°53′ W., on June 20, the work progressing from north to south. Work was interrupted on June 23 during the occupation of station 3019, when the *General Greene* was ordered to search for a berg reported in 41°45′ N., 48°40′ W., until relieved the following day by the *Champlain*. The berg was located at 1450 on June 24 and the *General Greene* stood by it until relieved by the *Champlain* at 2015 when the *General Greene* proceeded toward the next oceanographic station arriving there and resuming work on June 25. The work of collection of data was completed at station 3048 located at 42°17′ N., 50°41′ W., on June 30, a total of 55 stations having been occupied. The resulting current map was then constructed, being completed and delivered aboard the *Champlain* on July 1, 13 hours after the last station was occupied. The *General Greene* then returned to St. John's where she arrived on July 3.

Thus 201 oceanographic stations were occupied during the ice-patrol season. After completing the last map the *General Greene* was released from further mapping of the Grand Banks region for a short post-season cruise between southern Labrador and southern Greenland. During this cruise 25 additional oceanographic stations, disposed in the form of a single section from South Wolf Island to Cape Farewell, were occupied from July 10 to July 15. The temperature and salinity

data collected at the 226 stations occupied during the season and on the post-season cruise are presented in the oceanographic table in this bulletin.

The equipment and methods of measurement were the same as in 1938. Calibration titrations were performed by James F. Flannery, seaman, first class. Routine salinity bridge measurements were made by Flannery, Albert H. Hauser, seaman, first class, and Leonard T. Quattlebaum, seaman, second class. Other assistants in the observational work were Thomas C. Crabe, yeoman, second class, and Henry A. Minard, surfman. At the 201 stations occupied during the season the extent and nominal depths of the serial observations of temperature and salinity were the same as in 1938. At all stations on the post-season cruise the measurements extended to as near bottom as was practicable.

As in years past, a program of intercomparison of the reversing thermometers was carried out through periodic shifts in thermometer pairs in order to check on the functioning of these instruments. In all, 1,414 individual comparisons were investigated, the probable differences between the corrected readings of a pair of thermometers varying among the different groups from 0.003° to 0.020° C. and being 0.011° C. for the entire 1,414 comparisons. The observed temperatures are therefore considered to be accurate to 0.01° C.

An error in standardization of the salinity bridge affecting the fourth map and the post-season cruise was introduced by a questionable intermediate- or sub-standard but was detected and verified by the careful titration of 85 actual sea-water samples. These corrections, as well as the final standardization adjustments for the rest of the season, have been made before tabulation of the data and construction of the current maps. Near the end of the post-season cruise, 1 of the cells of the salinity bridge became inoperative through short-circuiting of its connections by a brass chip in the oil bath. Following the return of the equipment to the shore laboratory the bridge was disassembled, cleaned, and reassembled and its calibration curve then redetermined by numerous measurements, by both bridge and titration methods, on 7 oil-sealed carboys of actual sea water, approximately equally distributed over the salinity range of 32.6°/₀₀ to 36.6°/₀₀. The calibration curve resulting is expressed by the equation:

$$S=10100.637/(204.475+M)-4.671$$

where S represents salinity in parts per thousand and M represents the resistance, in ohms, of the X arm of the salinity bridge as given by the dial readings at balance. The bridge measurements, which were made in the same manner as routine measurements are made at sea, had an uncertainty of ± 0.003°/₀₀ to ± 0.004°/₀₀ salinity. This is regarded as a measure of the precision of the method, the accuracy of

course being no greater than that of the titration method used in calibration.

The current maps prepared during the season as well as the map showing current conditions on the post-season cruise were made following the procedure used in the past several years, the season's maps being referred to the 1,000-decibar surface and the post-season map being referred to the 2,000-decibar surface.

Figure 20 shows the current map resulting from the first survey, made between March 30 and April 8. This map shows several striking abnormalities. Both the strength and breadth of the Labrador Current along the eastern slope of the Banks are unusual and even in the absence of an exact knowledge of the volume of flow involved can be said to be responsible for the considerable southeastward extension of the cold mixed water tongue which, defined on this chart by the 971.1-dynamic meter isobath, reaches to about 41° N., 48° W. This tongue of cold water was a characteristic of the 1939 ice season and its extent as shown in this figure, in spite of the fact that the Atlantic Current is seen to be flowing with unusual strength unusually far north for this time of year, indicates the abnormally large volume of flow of the Labrador Current immediately preceding and during the period of this survey. Other notable features of figure 20 are the early development of the Grand Banks whorl and the comparative freedom of the current pattern from irregular meanderings.

The dynamic current map resulting from the second survey, made April 23 to May 2, is shown in figure 21. In this figure the general pattern of the preceding survey is recognizable, but many changes are to be noted. The northward thrust of the mixed water on the left-hand side of the Atlantic Current north of latitude 44° N., had moved westward toward the Banks about 30 miles. This apparently blocked some of the southward flow of low dynamic height, forcing the southeastward bulge of the contour lines in the northeastern part of the map. This southeastward intrusion of colder water was no doubt assisted by westerly and northwesterly winds during the interval between surveys. The great strength of the Labrador Current found in the first survey was still in evidence and one of the results of this continued flood of Labrador Current water was the widening and further extension of the tongue of cold mixed water which in the first survey reached to about 41° N., 48° W. Another result was the encroachment of Labrador Current water on the shallow waters of the southern end of the Grand Banks. At the southwestern corner of the map a complicated current pattern was found and while the available observations are open to more than one interpretation, it seems certain that the corner station was located in a mixed water pool which had become detached from the main body of mixed water to the eastward. Whether from a decrease in the strength of the Gulf Stream or from

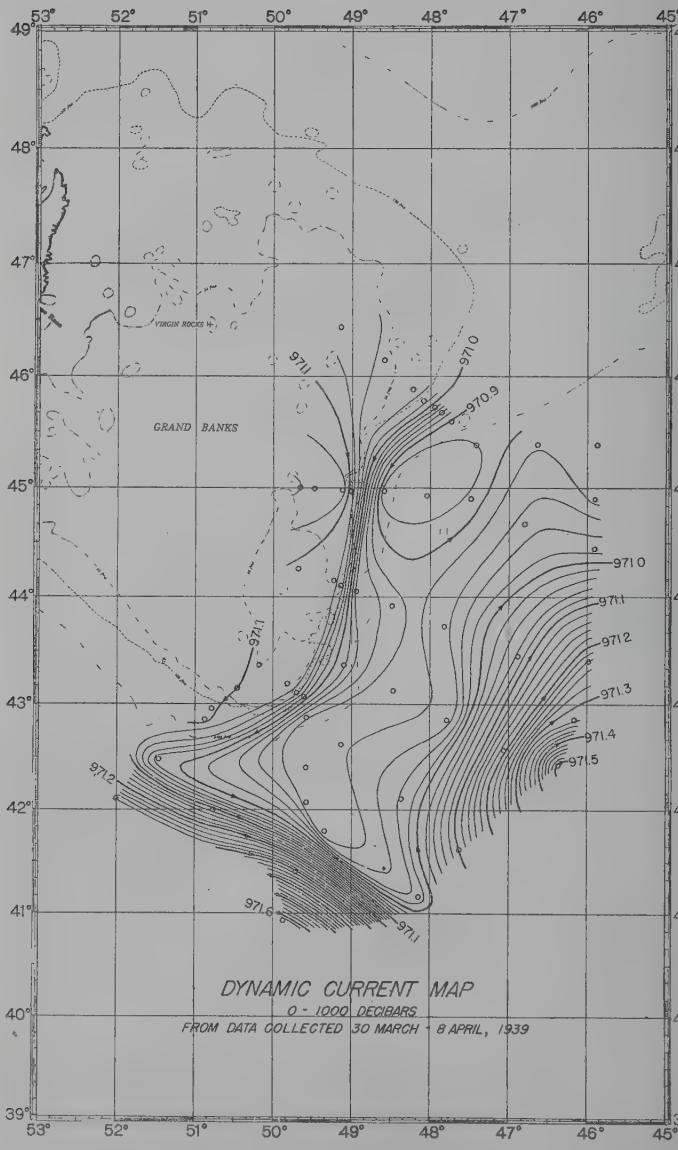

FIGURE 20.—Dynamic current map, from data collected March 30–April 8, 1939.

the great quantity of Labrador Current water entering this area or from both causes, the Gulf Stream south of the Grand Banks retreated

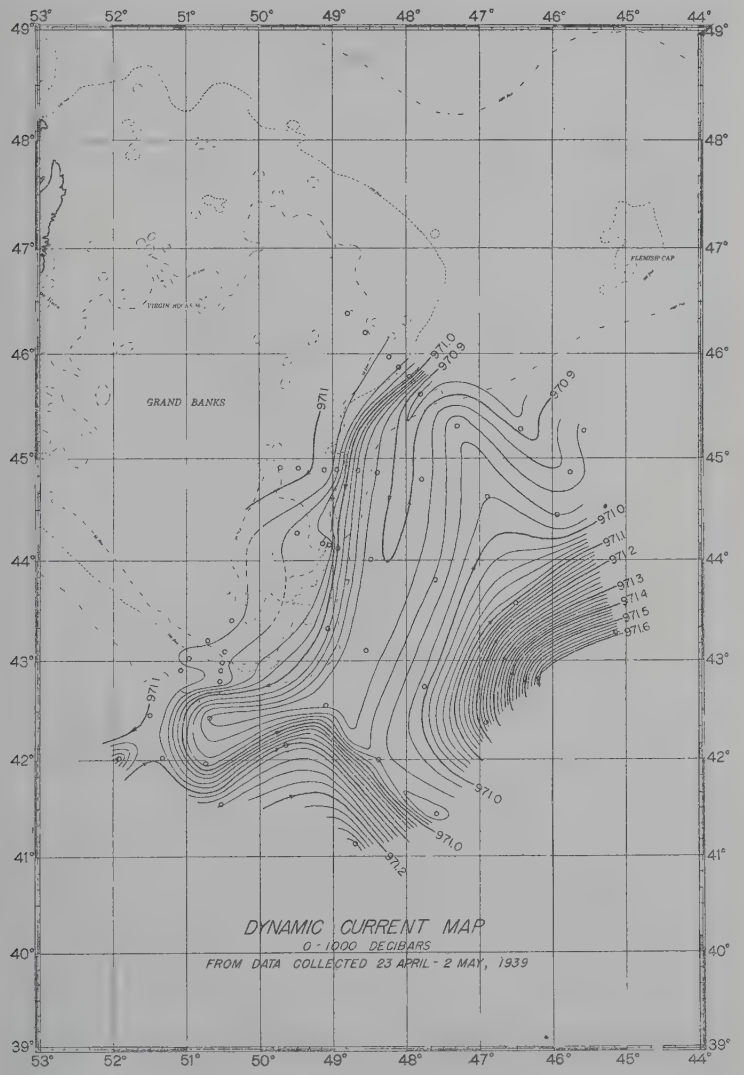

FIGURE 21.—Dynamic current map, from data collected April 23–May 2, 1939.

southward during the interval between the two surveys. At the eastern edge of the map, centered at about 43° N., 46° W., the Atlantic Current maintained its position.

Figure 22 shows the results of the third survey. As previously noted, this was planned to be a double survey in which the area was to be remapped as quickly as possible. The solid lines show the map resulting from the early work and the broken lines represent conditions found about a week later. To avoid crowding, the lines usually drawn for every 2 dynamic centimeters have been omitted in the region of the swifter currents. Considering the solid lines of figure

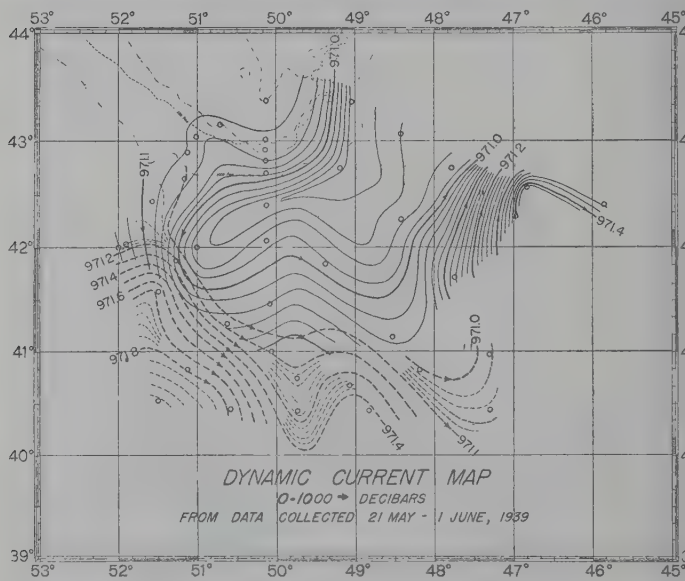

FIGURE 22.—Dynamic current map, from data collected May 21–June 1, 1939

22 with reference to the previous survey as illustrated by figure 21 it is seen that south of the Tail of the Banks the area of cold mixed water grew considerably in extent, the isobath of 971.1 dynamic meters moving from a latitude of about 42° N., at longitude 50° W., in figure 21 to latitude 41° N., at the same longitude in figure 22 (solid lines). During the same period the tongue of cold mixed water extending southeastward again increased in width and extent. The Atlantic Current border in the eastern part of the map showed a slight gain to the westward as compared with the previous map, but the extreme easternmost station indicated that northward of the limits of the survey the cold mixed water had increased greatly in volume. The Labrador Current was still flowing with unusual strength. Comparing the first part of the survey (solid lines) with the second part (broken lines) it will be seen that during the week which elapsed between the two parts of the survey the Gulf Stream had made a

considerable gain to the northeast in the western part of the area. This was not simply a case of only the northern edge of the Gulf Stream spreading out to the north for its northward migration was backed up by the major portion of the current as is borne out by the fact that the volume of flow computed between stations 2983 and 2993 with reference to the 1,500-decibar surface was 49.9 million cubic meters per second. This advance of the Gulf Stream was not caused by any decrease in the amount of cold mixed water supplied by the Labrador Current but instead the advance took place in spite of the continued growth of the quantity of cold water. This is evidenced by that part of the map eastward of about longitude 50° W. Here we see the northward hump in the isobaths displaced eastward from about longitude 49°45′ W., to about longitude 49°00′ W. Eastward of this northward hump in the isobaths the further southeastward extension of the cold mixed water compensates for the reduction in area covered by this type of water in the western part of the map, the isobath of 971.04 dynamic meters having been extended southeastward some 60 miles. The second part of this survey was probably made at about the time of the extreme southeastward extension of the area of cold mixed water.

The current map resulting from the fourth survey is shown in figure 23. Although following its seasonal diminution the Labrador Current was still flowing with strength and south of the Banks reached a western limit of about longitude 51°30′ W. No comparison with earlier conditions can be made in the area north of latitude 44°N., since this region was not covered in the previous survey. The large quantity of cold mixed water whose pronounced southeastward extension had characterized the entire season had begun its northward retreat. The southern extreme of the isobath of 971.1 dynamic meters which had been well south of latitude 41° N., and outside the limits of the surveys since early April had moved northward to about latitude 41°20′ N., and the end of the tongue of cold mixed water had intertwined cyclonically with a tongue of Atlantic Current water between latitudes 42° N., and 43° N. This intertwining pattern is considered to be a transitonal stage in the assimilation of the cold mixed water. The next stage is probably the establishment of a closed whorl. The current pattern of intertwining tongues shown in figure 23 was verified by the drift of a berg in this vicinity. Attention is called to this feature of the map because, although the existence of such current patterns as transitory phenomena has long been suspected, this is the first time that such a clearly defined and unmistakable pattern of this type has been mapped in the vicinity of the Grand Banks.

In continuation of an investigation of the seasonal variations in the volume of flow of the Labrador Current in the Grand Banks sector, an analysis was made of all the occupations of sections T, U, and W

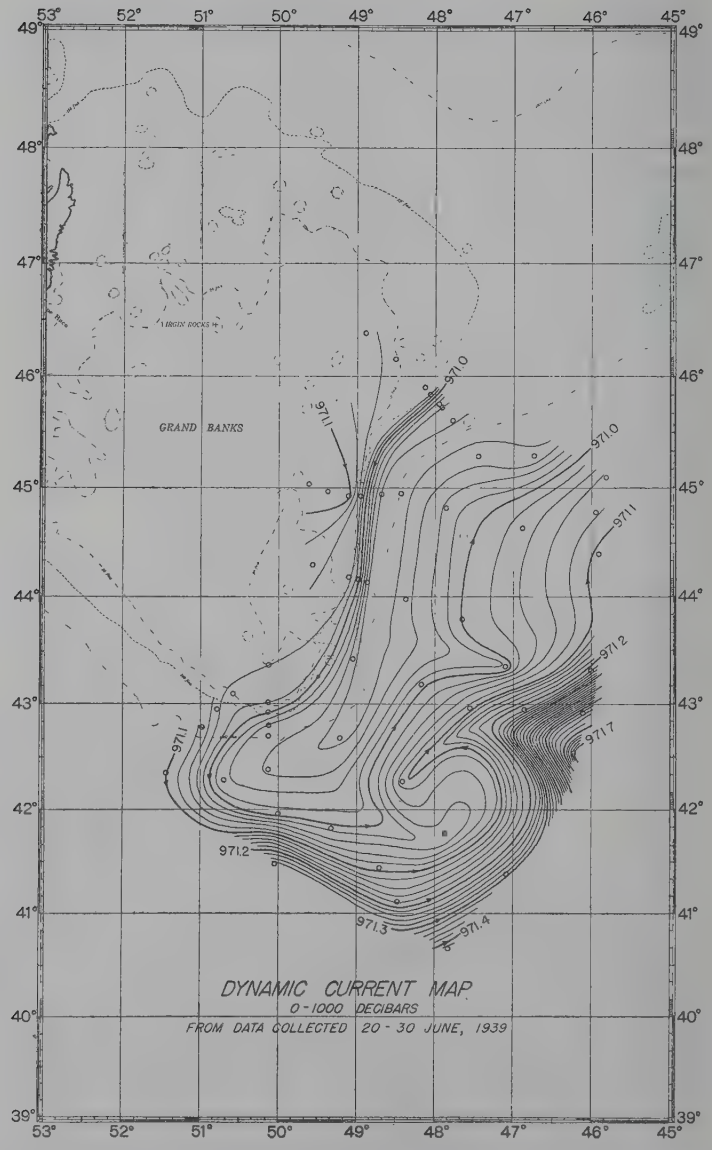

FIGURE 23.—Dynamic current map, from data collected June 20–30, 1939.

occurring during 1939. These sections, which have been repeatedly occupied and have formed the basis of earlier discussions in previous bulletins of this series are defined as follows: Section T, running southeasterly from about 46°20′ N., 49°00′ W.; section U, running east and west at about the 45th parallel; and section W, running south off the Grand Banks in about longitude 50° W. During 1939 sections T and U were occupied 3 times each and section W was occupied 4 times. For purposes of comparison the volume of flow, mean temperature, and minimum observed temperature are given in table 1 for all occupations of these sections from and including 1934.

TABLE 1.—*Showing volume of flow in million cubic meters per second, mean temperature in ° C., and minimum temperature in ° C., of the Labrador Current in the Grand Banks region*

	Mar. 16 to Apr. 15			Apr. 16 to May 15			May 16 to June 15			June 16 to July 15		
	Volume	Mean temperature	Minimum temperature	Volume	Mean temperature	Minimum temperature	Volume	Mean temperature	Minimum temperature	Volume	Mean temperature	Minimum temperature
Section T:												
1934				1.8	1.53	−1.66	1.5	2.6	−1.72	1.5	3.3	−1.70
1935				2.1	1.67	−1.71						
				4.1	2.85	−1.56	2.71	2.06	−1.50			
1936	1.86	0.98	−0.75	3.23	1.83	−0.43	3.15	2.90	−1.47			
1937				3.53	1.83	−1.49	1.96	1.55	−1.22	1.88	2.19	−1.25
1938				6.70	4.26	−1.79	3.88	1.85	−1.67	4.30	1.74	−1.62
1939	5.71	2.12	−1.65	4.55	0.74	−1.68				2.62	1.44	−1.53
Average	3.78	1.55	−1.20	3.72	2.10	−1.47	2.64	2.19	−1.52	2.58	2.17	−1.52
Section U:												
1934				3.48	1.11	−1.37	3.11	1.56	−1.70	0.84	1.32	−1.65
1935	3.7	2.0	−1.66	5.92	0.98	−1.24	4.46	1.75	−1.28			
1936	7.20	2.31	−0.82	6.69	1.06	−0.94	3.90	3.14	−1.23			
1937	3.54	1.54	−1.29	5.80	1.90	−1.56	2.29	1.72	−1.29	3.02	1.81	−1.41
1938	5.62	2.16	−1.20	6.34	5.66	−0.71	5.14	3.80	−1.43	4.78	1.87	−1.64
1939	9.01	1.31	−1.51	7.15	1.60	−1.55				7.74	1.64	−1.61
Average	5.81	1.86	−1.30	5.90	2.05	−1.23	3.78	2.39	−1.39	4.09	1.66	−1.58
Section W:												
1934				1.17	1.19	−1.15	1.63	1.07	−1.58	0.86	4.35	1.68
1935	1.08	2.72	−1.12				3.87	1.47	−1.02			
1936				3.13	2.61	0.02						
				8.78	2.85	0.08						
1937	0.54	0.66	−0.29	5.48	2.33	−0.99				3.40	2.53	−0.76
1938	5.44	3.78	−0.83	5.78	4.75	0.39	2.76	3.73	1.18	5.07	2.42	−1.59
1939	7.43	1.76	−1.59	3.81	1.59	−1.52	5.93	1.82	−1.62	2.26	1.82	−1.49
Average	3.62	2.23	−0.96	4.69	2.55	−0.53	3.55	2.02	−0.76	2.90	2.78	−0.54

From this table it will be seen that the volume of flow was greater than the 6-year average at each occupation of each section with the exception of the second and fourth occupations of section W. It will also be noted that the mean temperature was lower than the average at each occupation of each section except the first occupation of section T. The minimum observed temperature, while not as significant as the volume of flow or mean temperature, was colder than the average through the year.

The seasonal variation in the volume of flow past sections T, U, and W during the 1939 season is shown graphically in figure 24. Similar curves drawn for other years have all shown a pronounced seasonal maximum occurring about the beginning of May. Figure 24 indi-

cates that this seasonal maximum occurred at or prior to the first survey, at least a month prior to the usual occurrence of the maximum volume of flow. Although the curves in figure 24 show a steady decrease in volume at section T and a slight secondary maximum late in June at section U, it will be noted that sections T and U were not occupied during the third survey and the shape of the curve for sec-

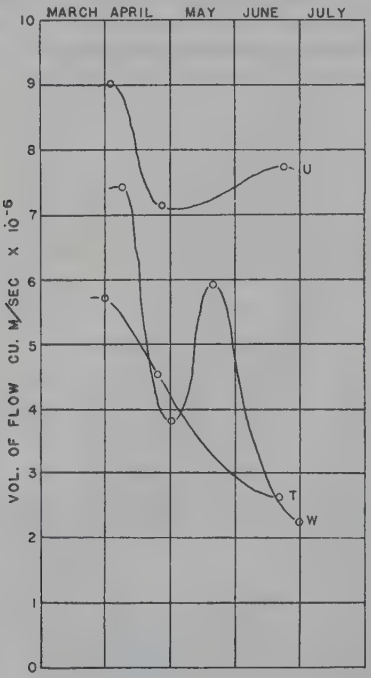

FIGURE 24.—Variation in the volume of flow of the Labrador Current in the Grand Banks region during the 1939 season.

tion W indicates the possibility that all three sections experienced a pronounced secondary maximum during May. Some support for this may be found in the reported location of the bergs. It is characteristic that for a short period early in the season some of the bergs put in their appearance southeast of the 1,000-fathom curve, fanning out from an axis extending southeasterly from about 46° N., 46° W. This characteristic invasion occurred early in the 1939 season and was repeated at about midseason. This may be a coincidence but it is reasonably possible that a considerable increase in the volume of flow of the Labrador Current is accompanied by a temporary flooding or

break-through southeastward across the usually effective natural barrier of the ridge extending southwesterly from Flemish Cap.

Salinity anomalies were again investigated with a view toward determining the departures from average conditions along the common boundary between the Labrador and Atlantic Currents. In the years 1934 to 1937, inclusive, the course of the horizontal projection of the surface of zero salinity anomaly in the axis of the intermediate anomaly maximum gave good results as indicating the boundary between Labrador Current water and Atlantic Current water. In 1938, because of the large volume of Labrador Current water present, the boundary line as indicated by this criterion was almost completely

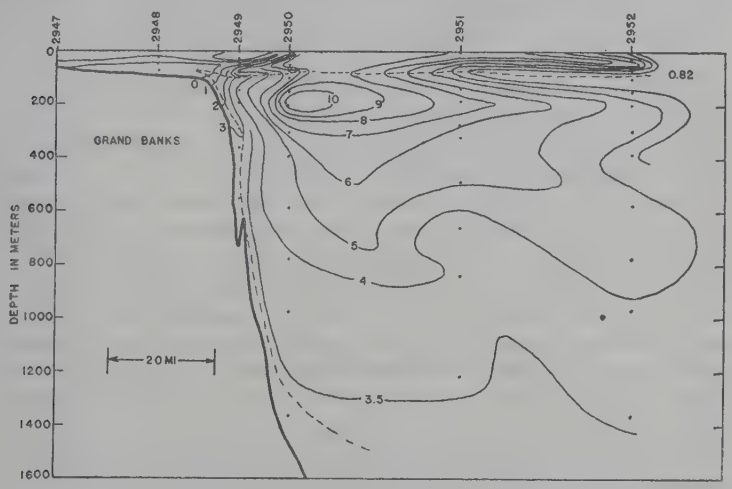

FIGURE 25.—Temperature profile southwest of Grand Banks, May 1–2, 1939.

outside the limits of the surveys. For the same reason the same was true in 1939, the line being outside the limits of the surveys at all but a very few stations.

In the past, isolated water masses of low temperature and salinity have been found from time to time south of the Grand Banks by the International Ice Patrol as well as by other investigators. In an attempt to learn more of the manner in which such water masses originate, a section running southwest from the Banks and occupied during the second survey was examined. Figure 25 shows a profile of temperature along this section. At station 2952 a mass of cold water, with the lowest observed temperature of 0.82° C. occurring at a depth of 75 meters, is typical of the isolated cold, fresh water masses that have repeatedly presented confusing problems to the surveyor attempting to map the currents in this region of complicated current

patterns. This mass of cold water has been partly separated from its source, the Labrador Current, by a thrust of Gulf Stream water from the northern border of the latter current. The separation of the cold water mass from the Labrador Current was not complete in the section under discusssion and the axis of minimum temperature, indicated by the broken line in figure 25, readily shows the origin of the cold water at station 2952, and demonstrates the manner in which similar but completely isolated cold-water masses are formed.

A secondary axis of minimum temperature is shown in figure 25 by the broken line roughly paralleling the bottom in the vicinity of the continental slope. This secondary temperature minimum is not as clearly defined in this section as the shallower axis but it serves to show the effect of cabbeling and downward mixing[2] along the border of the Labrador Current.

It is of interest to note here the order of magnitude of the possible increase in depth of a mixture of the contrasting waters at stations 2449 and 2450. At station 2449 at a depth of 150 meters the temperature and salinity were respectively 4.60° C. and 34.18°/₀₀ resulting in a value of σ_t=27.09. At station 2450 the same density surface lay at a depth of about 200 meters where the temperature and salinity were respectively 10.25° C. and 35.23°/₀₀ with a resulting σ_t of 27.10. If these two waters are mixed in equal proportions the resulting mixture will have a temperature of 7.42° C., a salinity of 34.705°/₀₀ and a resulting σ_t of 27.15. At station 2949 this density surface lay at a depth of about 187 meters or 37 meters deeper than the component from this station, and at station 2950 this density surface lay at about 220 meters or 20 meters deeper than its component.

In the discussion of the cold water mass at station 2952 its connection with the Labrador Current was traced entirely by means of temperatures. Figure 26 bears out the conclusion reached on the basis of temperature, that the water mass in question at station 2952 had its origin in the Labrador Current. In this figure lines of equal negative salinity anomaly have been drawn for the same stations shown in figure 25. Labrador Current water is characteristically cold and of low salinity, but further, it is characteristically of high negative salinity anomaly. On figure 26 the axis of negative salinity anomaly has been shown as a broken line. This figure clearly confirms the Labrador Current origin of the cold water mass at station 2952. A secondary axis of negative salinity anomaly has been indicated by a broken line and, like the secondary axis of minimum temperature in figure 25, it parallels the bottom near the continental

[2] This opportunity is taken to point out again that in this region the cabbeling and downward mixing which takes place along the current boundaries is characterized by a series of comparatively small depth increments usually accompanied by a relatively large horizontal component of motion so that conditions existing in any vertical section are largely the result of mixing all along the current boundary for a varying but considerable distance upstream.

slope. Incidentally, this admixture of Labrador Current water of negative salinity anomaly, spreading horizontally below about 1,200 meters as indicated in figure 26, may be a contributing factor in the establishment and maintenance of the layer of maximum salinity anomaly usually found off the eastern and southern slopes of the Grand Banks in intermediate depths of about 1000 meters.

The current maps regularly supplied to the patrol cutters during the ice-patrol season are maps of the dynamic topography of the sea surface relative to the topography at the 1,000-decibar surface. In the practical application and use of these maps it is assumed that

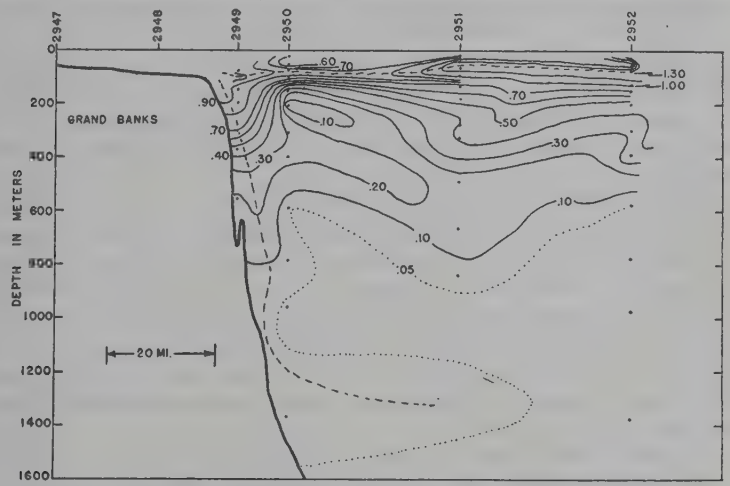

FIGURE 26.—Salinity anomaly profile southwest of Grand Banks, May 1–2, 1939.

they are absolute current maps. In other words, the assumption is that the 1,000-decibar surface is geocentric and motionless. Inasmuch as there are many practical difficulties in the way of verifying such an assumption by direct current measurements every effort has been made to examine indirect evidence bearing on the validity of the assumption. In recent years various criteria for a motionless reference surface have been proposed, that of the minimum oxygen layer provoking the most discussion. The selection of the layer of minimum oxygen as the motionless surface breaks down in the vicinity of the so-called polar front because it is in this vicinity that the layer of minimum oxygen reaches the sea surface. As much of the area in which the International Ice Patrol is interested lies to the north of this, the layer of minimum oxygen cannot be used.

Probably the best indication that an isobaric surface of intermediate depth is approximately motionless is the fact that year after year the bergs, acting as drift bottles, have been observed to follow,

in the main, directions and rates of drift agreeing with the dynamic topographic charts. The cases of discrepancy, some with regard to rate and some with regard to direction, point to the possibility of improving the current maps if our knowledge of the shape and location of the motionless surface can be increased sufficiently.

In 1935 the post-season cruise in the southern part of the Labrador Sea included subsurface measurements from surface to bottom at all stations. On the assumption that the isobaric surface in which the velocity was most nearly uniform was also the surface in which the velocity was most nearly zero, an investigation of the horizontal gradients of anomaly of specific volume indicated that in this region the most nearly motionless isobaric surface lay at a depth of about 2,000 meters.[3] With 2,000 decibars as the reference surface, deep-level dynamic topographic charts were constructed and proved to be in agreement with the circulation of the deep and bottom water deduced from charts of the bottom temperature made from this same survey.

Further evidence regarding the location and shape of the motionless surface in an adjacent area to the south, east of the Grand Banks, developed from the 1937 post-season cruise in this vicinity. The horizontal distribution of anomaly of specific volume, deep-level dynamic topographic charts, a volume transport balance above and below the assumed level of the motionless surface, and temperature-salinity correlations combined with the phenomenon of cabbeling, all agreed in pointing to the existance of a most nearly motionless surface at about 2,000 meters.[4]

Because it was indicated, on the assumption that the 2,000-decibar surface was the most nearly motionless, that in the 1937 survey the most rapid motion of the deep water occurred in the 3,500-decibar surface, the dynamic topography of the latter surface referred to the 2,000-decibar surface has been shown in figure 27 in comparison with a chart showing the distribution of potential temperature in the isentropic surface of $\sigma_{t\varphi}=27.90$. This potential density surface was selected for isentropic analysis because its depth is approximately the same as that of the 3,500-decibar surface. The axis of minimum temperature is the most striking feature of figure 27 and has been shown as a heavy broken line. It indicates the flow of the cold deep water from the Labrador Sea southward beneath the Atlantic Current. This is the same general picture of the circulation of the deep water that is given by the topographic chart at the left. The similarity of the two parts of figure 27 is considered to be a strong confirmation of the approximation to zero velocity at the 2,000-decibar

[3] Soule, Floyd M. International Ice Observation and Ice Patrol Service in the North Atlantic Ocean—Season of 1936. Oceanography, pp. 46–50, U. S. Coast Guard Bull. No. 26. Washington, 1938.

[4] Soule, Floyd M. International Ice Observation and Ice Patrol Service in the North Atlantic Ocean—Season of 1937. Oceanography, pp. 83–92, U. S. Coast Guard Bull. No. 27. Washington, 1938.

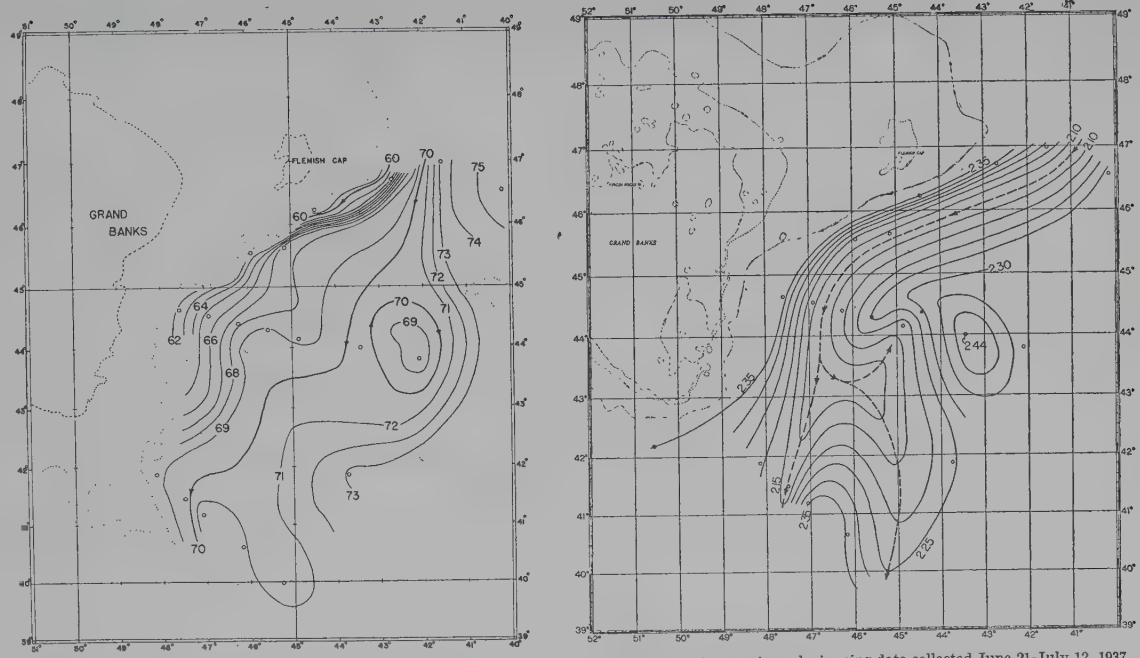

FIGURE 27.—Comparison of deep-water circulation as deduced from Bjerknes formulae and from isentropic analysis using data collected June 21–July 12, 1937. Left: Dynamic topography at 3,500 decibars relative to 2,000 decibars. Right: Potential temperature at isentropic surface of $\sigma_{tp}=27.90$.

surface since this is the reference surface used in the construction of the dynamic topographic chart shown. Because of the wide spacing of the stations, details of circulation cannot be derived from either part of figure 27. However, this much is regarded as certain: That the axis of minimum temperature is well defined and the southward flow clearly indicated. There is a choice open as to whether the axis passes east or west of the central station at the north end of the diagram. In the isentropic analysis the axis has been shown as passing east of this central station in order to preserve the simplest diagram. In the dynamic chart the axis seems to pass to the west of this central station. The main point is that the two circulation pictures are in general agreement.[5]

In considering surfaces of equal density such as in an isentropic analysis one of the steps involved is the plotting of lines of equal σ_t on temperature-salinity coordinates. It has been found useful to work with two open-scale curves. In the first curve temperature is plotted against D for the value of σ_t being considered, where D is defined by the equation $\sigma_o = \sigma_t + D$. For the construction of such a curve table 2 gives appropriate values for whole degrees of temperature from $-2°$ to $15°$ C. and for various values of σ_t covering the range usually encountered in the Ice Patrol area, derived by interpolation from page 46 of Knudsen's Hydrographical Tables.

Table 2.—*Values of D where* $\sigma_o = \sigma_t + D$.

T \ σ_t	27.2	27.3	27.4	27.5	27.6	27.7	27.75	27.8	27.9
−2	−0.070	−0.070	−0.071	−0.072	−0.073	−0.074	−0.074	−0.074	−0.075
−1	−.043	−.043	−.044	−.044	−.044	−.045	−.045	−.045	−.046
0									
1	.057	.057	.058	.058	.058	.059	.059	.059	.060
2	.127	.128	.129	.130	.130	.131	.131	.132	.132
3	.212	.213	.214	.216	.217	.218	.218	.219	.220
4	.310	.311	.313	.314	.315	.317	.318	.318	.320
5	.421	.422	.424	.426	.428	.430	.430	.431	.433
6	.545	.547	.549	.552	.554	.556	.557	.558	.560
7	.681	.684	.686	.688	.691	.694	.695	.696	.698
8	.830	.832	.835	.838	.841	.844	.845	.846	.849
9	.991	.994	.997	1.000	1.003	1.006	1.008	1.009	1.012
10	1.163	1.166	1.170	1.173	1.176	1.180	1.182	1.183	1.187
11	1.347	1.351	1.354	1.358	1.362	1.365	1.367	1.369	1.372
12	1.543	1.547	1.551	1.554	1.558	1.562	1.564	1.566	1.570
13	1.748	1.753	1.757	1.761	1.765	1.769	1.772	1.774	1.778
14	1.966	1.970	1.975	1.979	1.983	1.988	1.990	1.992	1.997
15	2.194	2.198	2.203	2.208	2.213	2.218	2.220	2.222	2.227

In the second curve σ_o is plotted against salinity. For facility in plotting such a curve Knudsen's formulae relating chlorinity and σ_o and chlorinity and salinity have been combined to give the following relationship between salinity and σ_o, where S represents salinity in parts per thousand:

[5] For further details see Soule, Floyd M. Consideration of the Depth of the Motionless Surface Near the Grand Banks of Newfoundland. Jour. Marine Res., vol. II, No. 3, pp. 169-180. New Haven. January 17, 1940.

$$\sigma_o = -0.0934 + 0.81487S - 0.0004825S^2 + 0.00000677S^3$$

From this relationship corresponding values of σ_o have been computed for each 0.1 °/₀₀ salinity over the range from 32.5 to 36.5°/₀₀ and are given in table 3.

TABLE 3

S	σ_o	S	σ_o	S	σ_o	S	σ_o
32.5	26.113	33.6	26.998	34.6	27.804	35.6	28.610
32.6	26.193	33.7	27.079	34.7	27.884	35.7	28.691
32.7	26.274	33.8	27.159	34.8	27.965	35.8	28.771
32.8	26.354	33.9	27.240	34.9	28.046	35.9	28.851
32.9	26.435	34.0	27.320	35.0	28.126	36.0	28.932
33.0	26.515	34.1	27.401	35.1	28.207	36.1	29.013
33.1	26.596	34.2	27.482	35.2	28.288	36.2	29.094
33.2	26.676	34.3	27.562	35.3	28.368	36.3	29.174
33.3	26.757	34.4	27.643	35.4	28.449	36.4	29.255
33.4	26.837	34.5	27.723	35.5	28.529	36.5	29.336
33.5	26.918						

Using the value of σ_o derived from the first curve, the second curve gives the appropriate value of salinity corresponding to the given temperature and the chosen value of σ_t. From a number of points so derived a curve of constant σ_t can be drawn on a temperature-salinity plot.

The first survey of the season was subjected to a shallow-water isentropic analysis to see if the circulation pattern indicated by such an analysis would differ materially from that given by the dynamic topography and to get information on the order of magnitude of the range in depth of such an isentropic surface over the area involved. The surface of $\sigma_t = 27.2$ was selected for analysis as this was the shallowest surface covering the entire area of the survey. Temperatures and salinities at this surface and the depths of the surface were determined at each station of the survey at which the density was sufficiently great. Both the temperature and salinity distributions on the surface of $\sigma_t = 27.2$ gave circulation patterns in general agreement with that given by the dynamic topography. The depth of the surface considered varied from 0, in the region of lowest dynamic height in the northern part of the survey, to 660 meters, in the region of highest dynamic height in the southern part of the survey in the northern edge of the Gulf Stream. At the shallower stations on the Grand Banks side of the Labrador Current the water was lighter than the selected value of $\sigma_t = 27.2$, this surface intersecting bottom beneath the Banks half of the Labrador Current.

An interesting feature, which has an important bearing on the quantity of berg ice in the Grand Banks region and whose full significance cannot be determined without further study, developed from the shallow isentropic analysis of the first survey. The temperature-salinity curves for the individual stations fell into three distinct groups. One of these was the warm-water group having the characteristics of Atlantic Current water and this was anticipated. That the colder

water stations fell into two correlation groups instead of being scattered from the Atlantic group to the negative salinity-anomaly limit was an unexpected development because the Labrador Current off the Labrador coast is characterized by such a scattering which arises from the typical temperature minimum with approximately horizontal isotherms being intersected by inclined isohalines with the salinity decreasing shorewards. Hence it was surprising to find that the temperature-salinity curves for all the individual stations in the Labrador Current in the Grand Banks region occupied during the first survey followed a definite correlation. The third group was composed of stations taken in the area of mixed water between the Labrador Current and the Atlantic Current. This group of mixed-water stations also followed a definite correlation between temperature and salinity, the correlation curve being located between those for Labrador Current water and Atlantic Current water and closer to the former than the latter. The correlation curves for the Labrador Current water and the mixed water are shown in figure 28. An approximate depth scale in meters has been shown on each of the curves. Southwest and south of the Tail of the Grand Banks the width of the area between the Labrador and Atlantic Currents and occupied by the mixed water was less than the interval between stations. In other words the temperature-salinity characteristics changed abruptly from Labrador Current to Atlantic Current in going from one station to an adjacent station. However, east of the Grand Banks the width of the area of mixed water was considerable, averaging about 80 miles. The shape of the mixed-water area may be interpreted as verifying other indications that the region just south of the Grand Banks is one in which the mixing of the Labrador and Atlantic Currents is very active. The fact that the temperature-salinity correlation curve for the mixed water is much nearer that for Labrador Current water than for Atlantic Current water is probably explained by the direction of motion of the mixed water being counter to that of the Labrador Current water and similar to that of the Atlantic Current resulting in a greater further admixture of the former than of the latter. It is emphasized that the foregoing developed from the study of a single survey and that generalizations cannot be made on a sound basis until a number of such surveys have been investigated.

One respect in which it is particularly premature to draw general conclusions from this single survey is in regard to the part of the Labrador shelf or slope traversed by the Labrador Current found in the Grand Banks region. From the standpoint of berg ice this is a most tempting field for speculation because of the composition of the Labrador Current of a frigid portion over the shelf and a relatively warm portion over the slope off the Labrador coast, because of the major mortality suffered by any berg crop en route to the Grand Banks,

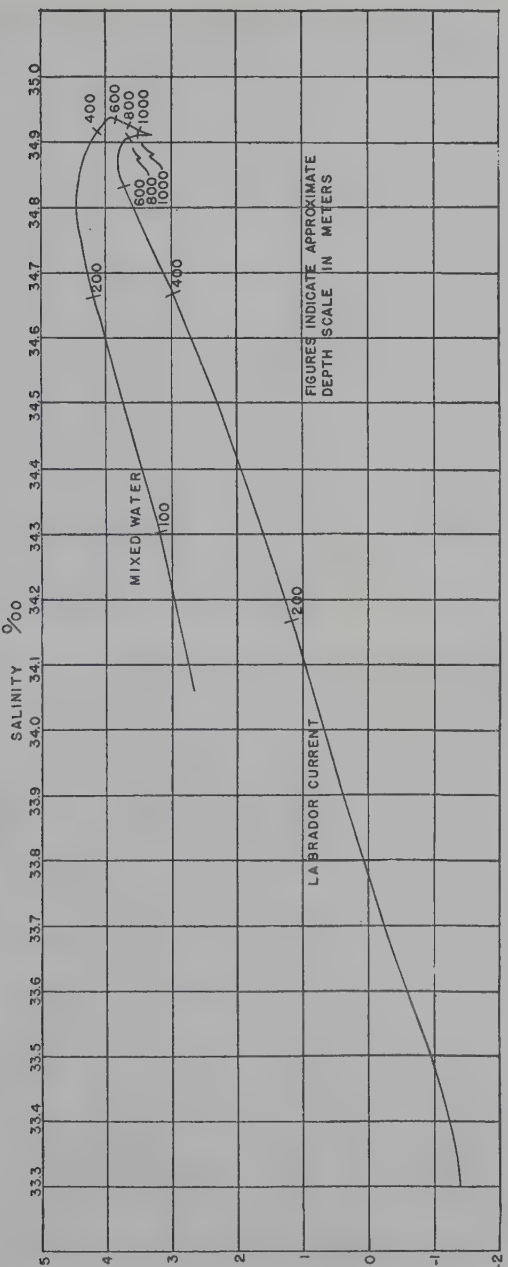

FIGURE 28.—Temperature-salinity correlation curves for Labrador Current and mixed water.

and because of the resulting critical balance between grounding of the bergs in the cold shallow water and the deterioration from melting in the warm deeper water. Thus it will be seen that a shift of the Labrador Current in a direction normal to the Labrador Coast will have an important effect on the quantity of berg ice appearing in the Grand Banks region. Such a shift took place in 1939 and is traceable to the departure from average wind conditions along the Labrador coast during the preceding winter. Monthly charts showing the departure from normal of barometric pressure indicated that during the winter of 1938–1939 there existed an abnormally strong off-shore component of winds along the Labrador coast. On the basis of this the ice forecast for the 1939 season was qualified as follows: "As the Smith formulae consider only transportation under average conditions of temperature, it is anticipated that the number of bergs actually drifting south of latitude 48° N., will exceed the above-mentioned figure of 500 because the prevalence of off-shore winds along the Labrador coast has probably afforded a colder than usual deep-water path for the bergs and thus reduced the percentage mortality during this part of the journey. For similar reasons it is expected that the east coast of the Avalon Peninsula of Newfoundland will be freer of bergs than is usual during the months of May and June at which season their number is usually at a maximum." Both parts of this qualitative prediction proved correct.

No opportunity for determining the magnitude of the offshore shift of the Labrador Current was available until the post-season cruise, several months after the winds probably had their maximum effect. Figure 29 shows the temperature section found in the vicinity of the slope off South Wolf Island, Labrador, during July 1939 in comparison with the thermal conditions which were found during July 1938. An inspection of figure 29 shows that the eastern (offshore) limits of the −1°, 0°, 1°, 2°, and 3° isotherms underwent offshore horizontal displacements of 6, 8, 8½, 8, and 6 miles respectively while the warm axis at 200 meters was 10 miles farther offshore in 1939 than in 1938. From this it will be seen that in the vicinity of the slope similar thermal characteristics were found about 8 miles farther offshore in 1939 than in 1938. In this locality a horizontal change of 8 miles means a change in depth from 370 meters to 940 meters. Differently expressed, the effect of this shift on the berg mortality is to reduce the amount of melting suffered by a berg traveling the same course. The upper 20 meters is occupied by a steep temperature gradient with the surface temperature varying greatly from time to time. Considering only depths from 20 meters to 200 meters in a position near the slope, the average temperature of the water column was 0.5° in 1939 compared with 2.0° in 1938 for the same location. Apparently, then, any prolonged departure from average conditions in the offshore component of

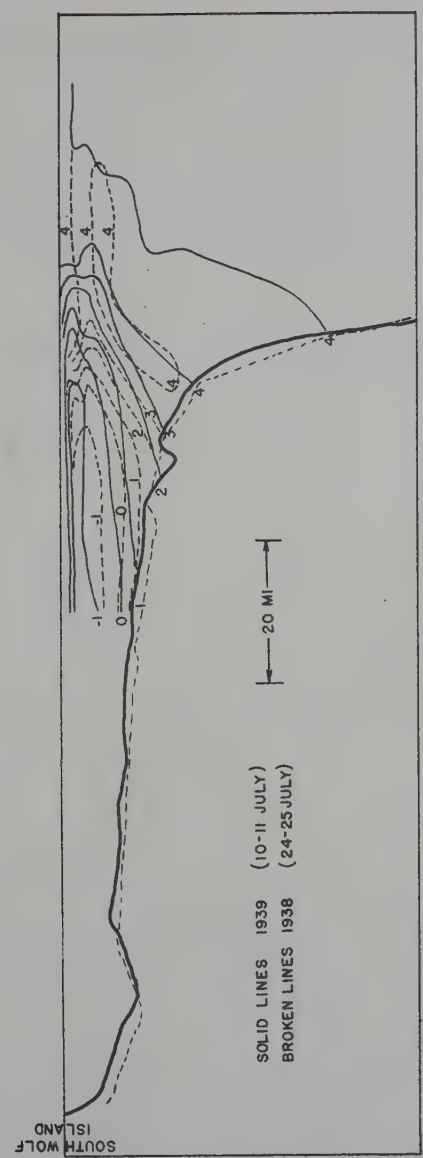

FIGURE 29.—Comparison of thermal conditions off South Wolf Island, Labrador, during 1938 and 1939 showing the effect of off-shore winds in producing a horizontal displacement of the Labrador Current.

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the winds along the Labrador Coast will have a decided effect on the crop of berg ice appearing in the Grand Banks region. Quantitative correlations between these two phenomena or between any of the associated intermediate steps between cause and effect have yet to be determined.

On the post-season cruise the section from South Wolf Island, Labrador, to Cape Farewell, Greenland, which has been occupied in other years, was repeated. Figure 30 shows the temperature distribution along this section. As pointed out above, the Labrador Current was shifted slightly offshore by abnormal wind conditions. The most

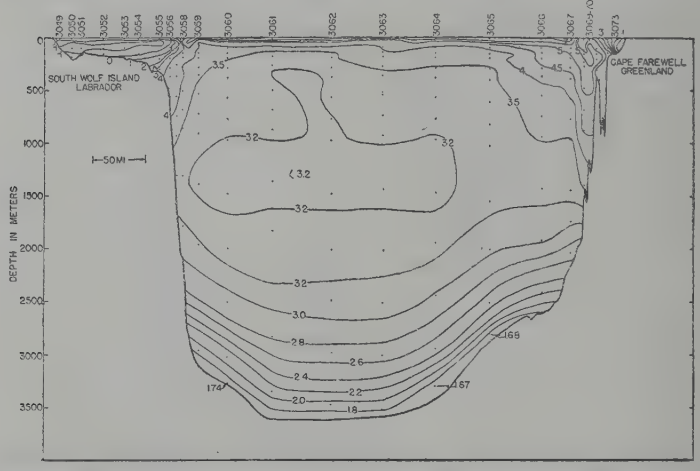

FIGURE 30.—Temperature distribution between South Wolf Island, Labrador, and Cape Farewell, Greenland, July 10–15, 1939.

noticeable feature of figure 30 is the large area in the intermediate water having temperatures of less than 3.2°. This is a characteristic of this part of the Labrador Sea and is interpreted by Smith, Soule, and Mosby [6] as being a relic of the previous winter's chilling not completely erased by the mixing processes which follow with the advent of warmer weather.

Off the Greenland coast the warm water of the Irminger Current and the colder water nearer shore have a more complicated pattern than usual. This apparently is the result of part of the colder East Greenland Current water having been separated offshore from its main body. It will be noted that stations 3069 and 3070 are plotted as a single station in figure 30. After station 3069 was occupied it was necessary

[6] Smith, Edward H., Soule, Floyd M., and Olav Mosby. The *Marion* and *General Greene* Expeditions to Davis Strait and Labrador Sea, Scientific Results, Physical Oceanography. U. S. Coast Guard Bull. No. 19, pt. 2, p. 186. Washington, 1937.

to heave to for several hours on account of weather. Oceanographic work was resumed about 36 hours later and station 3070 was located about 15 miles east-southeasterly of station 3069 although both stations were about equally distant from the coast and had about the same depth of water. Average values of the two stations were used in the construction of figure 30 and in the dynamic computations.

The current situation existing during the post-season cruise is shown in figure 31 where the dynamic topography of the surface relative to

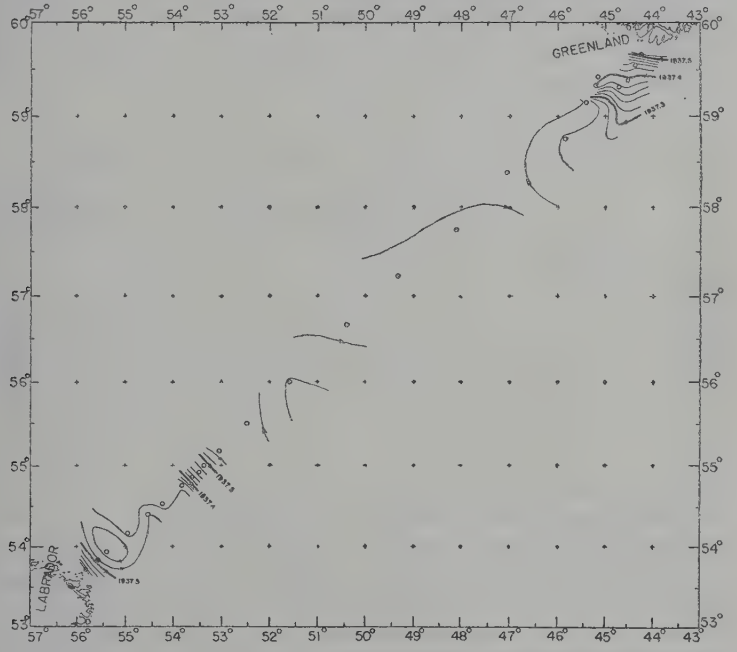

FIGURE 31.—Dynamic topography of surface relative to 2,000 decibars. Post-season cruise, July 10–15, 1939.

2,000 decibars has been indicated. Since the stations of the survey were disposed in the form of a single section the current pattern cannot be described with accuracy. However, figure 31 is of material help in interpreting a velocity profile along this section and arriving at reliable values for the volumes of flow of the Labrador and West Greenland Currents. Volumes of flow, mean temperatures, and heat transfers have been determined for 8 occupations of the section across the Labrador Current off South Wolf Island and for 10 occupations of the West Greenland Current off Cape Farewell. To facilitate comparison with conditions found in other years these results are listed in table 4. Except for the 1928 occupations by the *Godthaab* in May and the *Marion* in July–September and except for the March 1935 occupation

by the *Meteor*, all of the results tabulated are from the post-season cruises of the *General Greene*. Volumes of flow are given in millions of cubic meters per second, mean temperatures in degrees centigrade, and heat transfers in millions of cubic meter degrees centigrade The values given for the occupations prior to 1935 have not been as precisely determined as the later values and may be subject to further revision. Consideration of table 4 shows that in 1939 the Labrador Current off South Wolf Island was flowing with very nearly average volume, had very nearly the average mean temperature and transported heat at the average rate and that these elements were unaffected by the offshore shift discussed earlier in connection with figure 29.

TABLE 4

	South Wolf Island			Cape Farewell		
	Volume	Mean temperature	Heat transfer	Volume	Mean temperature	Heat transfer
May 1928				4.0	4.1	16.4
July–September 1928	5.1	3.3	16.5	4.4	5.5	24.1
1931	1.3	1.7	2.2	3.7	5.3	19.5
1933	7.60	3.41	25.90	5.94	4.19	20.39
1934	5.03	2.68	13.50	2.91	5.1	14.86
March 1935				7.5	4.0	30.0
August 1935	4.22	2.76	11.65	8.50	4.99	42.44
1936	3.32	1.27	4.22	6.37	4.05	25.83
1938	4.20	2.92	12.25	5.43	4.69	25.04
1939	4.56	2.69	12.27	6.31	4.19	26.46
Average	4.4	2.6	12.3	5.5	4.6	24.5

Table 4 shows the West Greenland Current at Cape Farewell to have been flowing with greater than average strength. As pointed out in Bulletin No. 28 of this series,[7] the unqualified mean temperature of the West Greenland Current at Cape Farewell for any single occupation of the section cannot be compared with the average of other occupations without misleading results. The reason for this is the considerable seasonal variation in temperature. Figure 53 of Bulletin No. 28 showed a smooth curve representing this seasonal variation. In 1939 the mean temperature of 4.19° C. was not only colder than the average, but also was 0.44° colder than the normal mean temperature for the time of year as indicated by this curve. As the curve was based on a small number of points its absolute values of temperature are questionable. Its shape, however, seems to be well defined and if the whole curve is too low or too high the errors involved in departures from normal mean temperatures will be constant. Because of this it is considered to be worth while to present a preliminary study of these variations having fundamental ramifications.

[7] Soule, Floyd M. International Ice Observation and Ice Patrol Service in the North Atlantic Ocean—Season of 1938. Oceanography. U. S. Coast Guard Bull. No. 28. Washington, 1940.

In figure 32 such departures from normal mean temperature have been plotted against time for each of the 10 occupations of the section. In the same figure the corresponding volumes of flow also have been plotted against time. It is pointed out that even with such infrequent observations, figure 32 shows a negative correlation in all but 1 of the 9 intervals. In other words, with the exception of the interval between the 1936 and 1938 occupations every time the volume of flow increased the mean temperature became colder with reference to the season of the year. It is quite possible that the conditions existing in 1937 were those of larger volume and lower temperature than in 1936 or 1938, in which case the correlation would be negative

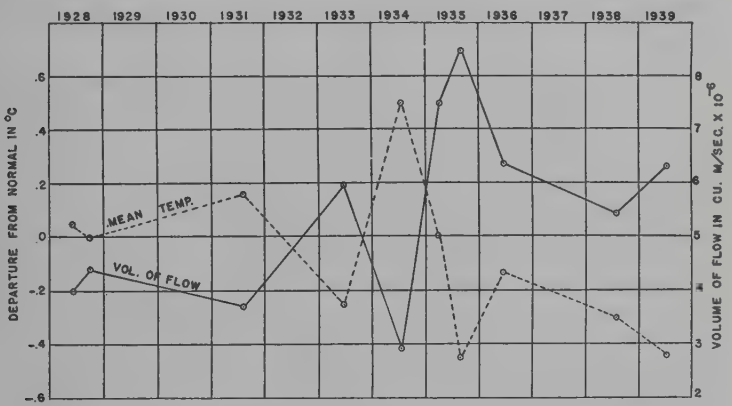

FIGURE 32.—Comparison of variations in the volume of flow of the West Greenland Current at Cape Farewell and departures of its mean temperature from normal.

throughout. The patent interpretation of this negative correlation is that fluctuations in the volume of flow of the West Greenland Current arise chiefly from fluctuations in the East Greenland Current rather than the Irminger Current.

Attention is drawn to the apparent trends toward greater volume of flow and lower temperature shown by the curves in figure 32 for the period from 1928 to 1939, the increase in volume approximating 2½ million cubic meters per second and the decrease in mean temperature about a half degree. These trends, if genuine, may be associated with the present phase of the Greenland climatic cycle which Jensen [8] says is now one of decreasing temperature.

SUMMARY

1. Four current surveys of the Ice Patrol area in the vicinity of the Grand Banks, made during the 1939 season, have been described.

[8] Jensen, Ad. S. Concerning a change of climate during recent decades in the arctic and subarctic regions from Greenland in the west to Eurasia in the east and contemporary biological and geophysical changes. Det. Kgl. Danske Videnskabernes Selskab. Biologiske Meddelelser XIV, 8. Copenhagen, 1939.

2. Computations of the volume of flow have been made and the results presented to show the seasonal variation of the Labrador Current during 1939 as compared with other variations found during the previous 5 ice seasons.

3. The boundary between Atlantic Current water and Labrador Current water, as delineated by the horizontal projection of the zero salinity anomaly surface at the intermediate salinity anomaly maximum, was investigated but found to be outside the limits of the 1939 surveys.

4. Profiles of temperature and salinity anomaly near the Tail of the Grand Banks have been used to clarify the genesis of the isolated cold-water masses frequently found in that vicinity, and incidentally to point out a partial cause of the intermediate salinity anomaly maximum.

5. A recapitulation of the various indicators of the shape and depth of the motionless surface in the Grand Banks region has been given and amplified by a further verification in the form of a deep-level isentropic analysis of data collected on the 1937 post-season cruise.

6. Tables of the difference between σ_o and σ_t for various values of temperature and density, and of σ_o corresponding to various values of salinity have been given to facilitate the plotting of lines of equal σ_t on temperature-salinity coordinates.

7. An analysis of the first survey showed the existence of definite temperature-salinity correlations for the mixed water and Labrador Current water in the Grand Banks region, and the correlations have been presented graphically.

8. A comparison between the thermal characteristics of the Labrador Current off South Wolf Island, Labrador, found in 1939 and 1938, has been presented to show the off-shore shift of this current resulting from abnormal winds during the winter of 1938–39, and to point out the effect on the mortality of bergs en route to the Grand Banks.

9. The volumes of flow, mean temperatures, and heat transfers of the Labrador Current at South Wolf Island and of the West Greenland Current at Cape Farewell, have been derived from observations made in 1939 and compared with seven previous occupations of the Labrador section and nine previous occupations of the Cape Farewell section. Results have been tabulated and particular emphasis placed on the seasonal variation of the temperature of the West Greenland Current in the interpretation of these results. Taking account of this seasonal variation a negative correlation has been found to exist between the mean temperature of the West Greenland Current and its volume of flow with the conclusion that fluctuations in its volume of flow arise chiefly from fluctuations in the East Greenland Current.

In the following table are given the data collected during the 1939 season and post-season cruises. The individual station headings give

the station number, date, geographic position, depth of water, and dynamic height of the sea surface above the reference surface used in the construction of the dynamic topographic charts shown in figures 20, 21, 22, 23, and 31. For stations 2848 to 3048, inclusive, the sea surface is referred to the 1,000-decibar surface and the depth of water is the uncorrected fathometer sounding based on a sounding velocity of 1,441.4 meters per second. For stations 3049 to 3073, inclusive, the sea surface is referred to the 2,000-decibar surface and the depth of water is the sonic sounding corrected for sounding velocity and draft, but not for slope. Where the depths of the scaled values are enclosed in parentheses the data are based on extrapolated vertical distribution curves of temperature or salinity or both. Asterisks appearing before observed temperatures indicate that these temperatures were determined from the depth of reversal and the corrected reading of an unprotected thermometer. The symbol σ_t signifies 1,000 (density-1) at atmospheric pressure and temperature t.

TABLE OF OCEANOGRAPHIC DATA

STATIONS OCCUPIED IN 1939

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
Station 2848; Mar. 30; latitude 46°26′ N., longitude 49°08′ W.; depth 70 meters; dynamic height 971.067 meters						
0	−0.75	32.76	0	−0.75	32.76	26.35
27	−0.76	33.64	25	−0.75	32.89	26.45
54	−0.79		50	−0.80	33.03	26.57
Station 2849; Mar. 30; latitude 46°08′ N., longitude 48°35′ W.; depth 86 meters; dynamic height 971.059 meters						
0	−1.03	33.01	0	−1.03	33.01	26.56
19	−1.05	33.05	25	−1.10	33.06	26.60
50	−1.30	33.11	50	−1.30	33.11	26.65
81	−1.34	33.13	75	−1.35	33.13	26.67
Station 2850; Mar. 30; latitude 45°53′ N., longitude 48°13′ W.; depth 112 meters; dynamic height 971.047 meters						
0	−1.64	33.03	0	−1.64	33.03	26.59
12	−1.33	33.29	25	−1.35	33.28	26.79
41	−1.35	33.42	50	−1.35	33.28	26.79
71	−1.38	33.28	75	−1.40	33.28	26.79
100	−1.30	33.29	100	−1.30	33.29	26.79

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
Station 2851; Mar. 30; latitude 45°47′ N., longitude 48°05′ W.; depth 229 meters; dynamic height 971.038 meters						
0	−1.64	33.21	0	−1.64	33.21	26.74
25	−1.62	33.11	25	−1.62	33.11	26.66
50	−1.65	33.15	50	−1.65	33.15	26.69
76	−1.31	33.41	75	−1.35	33.40	26.89
101	−0.79	33.58	100	−0.85	33.59	27.01
151	−0.20	33.61	150	−0.20	33.61	27.02
202	0.46	33.77	200	0.40	33.76	27.11
Station 2852; Mar. 30; latitude 45°43′ N., longitude 47°58′ W.; depth 723 meters; dynamic height 970.988 meters						
0	−1.64	33.29	0	−1.64	33.29	26.80
24	−1.63	33.28	25	−1.65	33.28	26.79
49	−1.63	33.33	50	−1.65	33.33	26.84
73	−1.63	33.35	75	−1.65	33.35	26.86
97	−1.64	33.43	100	−1.65	33.46	26.95
146	−1.30	33.89	150	−1.30	33.90	27.29
194	−1.19	34.02	200	−1.10	34.04	27.40
291	1.59	34.39	300	1.75	34.41	27.54
391	2.65	34.59	400	2.70	34.60	27.61
588	*3.27	34.79	600	3.30	34.80	27.72

Table of Oceanographic Data—Continued

STATIONS OCCUPIED IN 1939—Continued

Station 2853; Mar. 31; latitude 45°40′ N., longitude 47°52′ W.; depth 1,097 meters; dynamic height 970.941 meters

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	−1.59	33.35	0	−1.59	33.35	26.85
25	−1.55	33.35	25	−1.55	33.35	26.85
50	−1.02	33.44	50	−1.02	33.44	26.91
75	3.95	34.25	75	3.95	34.25	27.22
100	4.04	34.27	100	4.04	34.27	27.23
150	3.70	34.37	150	3.70	34.37	27.34
199	3.99		200	4.00	34.52	27.43
299	4.17	34.78	300	4.15	34.78	27.61
380	3.58	34.80	400	3.60	34.81	27.70
575	3.95	34.92	600	3.90	34.92	27.76
774	*3.61	34.92	800	3.60	34.91	27.78
975	3.44	34.89	1,000	3.40	34.89	27.78

Station 2854; Mar. 31; latitude 45°35′ N., longitude 47°44′ W., depth 1,573 meters; dynamic height 970.897 meters

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	1.93	33.93	0	1.93	33.93	27.13
23	2.70	34.04	25	2.75	34.05	27.17
47	3.08	34.10	50	3.10	34.11	27.19
70	3.50	34.19	75	3.60	34.22	27.23
93	4.55	34.34	100	4.50	34.35	27.24
140	4.13	34.41	150	4.15	34.44	27.34
186	4.16	34.59	200	4.15	34.63	27.49
279	4.12	34.80	300	4.35	34.90	27.69
306	4.40	34.92	400	3.95	34.91	27.74
471	3.76	34.90	600	3.70	34.92	27.79
645	*3.69	34.93	800	3.50	34.91	27.79
847	3.47	34.89	1,000	3.40	34.90	27.79
1,215	3.30	34.91				

Station 2855; Mar. 31; latitude 45°23′ N., longitude 47°25′ W.; depth 2,843 meters; dynamic height 970.880 meters

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	3.53	34.18	0	3.53	34.18	27.20
24	3.55	34.18	25	3.55	34.18	27.20
47	3.71	34.22	50	3.70	34.22	27.22
71	3.75	34.21	75	3.75	34.21	27.21
94	3.80	34.23	100	3.80	34.25	27.23
141	3.54	34.45	150	3.60	34.50	27.45
189	4.41	34.73	200	4.40	34.76	27.57
283	4.29	34.88	300	4.25	34.90	27.70
338	4.10	34.92	400	3.95	34.93	27.75
515	3.77	34.93	600	3.70	34.94	27.79
696	3.61	34.95	800	3.50	34.93	27.80
885	3.46	34.91	1,000	3.40	34.91	27.80
1,282	3.28	34.90				

Station 2856; Mar. 31; latitude 45°23′ N., longitude 46°38′ W.; depth 3,209 meters; dynamic height 970.919 meters

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	2.60	33.98	0	2.60	33.98	27.13
25	2.75	34.01	25	2.75	34.01	27.14
50	2.90	34.03	50	2.90	34.03	27.15
74	5.65	34.55	75	5.65	34.55	27.26
99	5.34	34.51	100	5.35	34.51	27.27
149	4.49	34.46	150	4.45	34.46	27.33
198	3.59	34.46	200	3.60	34.46	27.42
297	4.64	34.85	300	4.65	34.86	27.63
369	4.13	34.90	400	4.00	34.90	27.73
557	3.65	34.89	600	3.60	34.89	27.76
747	3.54	34.90	800	3.55	34.91	27.78
938	3.57	34.93	1,000	3.55	34.93	27.80
1,326	3.34	34.92				

Station 2857; Mar. 31; latitude 45°23′ N., longitude 45°52′ W., depth 3,438 meters; dynamic height 970.905 meters

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	4.89	34.12	0	4.89	34.12	27.01
25	4.90	34.10	25	4.90	34.10	27.00
50	4.15	34.24	50	4.15	34.24	27.19
75	3.89	34.25	75	3.89	34.25	27.22
100	3.83	34.26	100	3.83	34.26	27.24
150	3.61	34.34	150	3.61	34.34	27.32
201	4.42	34.64	200	4.40	34.63	27.48
301	4.13	34.83	300	4.15	34.83	27.66
367	4.03	34.88	400	4.00	34.90	27.73
554	3.84	34.94	600	3.80	34.94	27.78
744	3.57	34.93	800	3.55	34.93	27.80
936	3.45	34.93	1,000	3.40	34.93	27.78
1,329	3.29	34.91				

Station 2858; Mar. 31; latitude 44°53′ N., longitude 45°54′ W.; depth 3,612 meters; dynamic height 970.918 meters

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	3.02	33.96	0	3.02	33.96	27.08
23	2.95	33.96	25	2.95	33.96	27.08
46	3.01	34.00	50	3.00	34.00	27.11
70	2.91	34.02	75	2.90	34.03	27.15
93	2.97	34.06	100	3.00	34.07	27.17
139	3.15	34.17	150	3.25	34.21	27.25
185	3.66	34.45	200	3.85	34.54	27.45
278	4.45	34.84	300	4.30	34.85	27.66
286	4.26	34.81	400	4.20	34.92	27.73
434	4.15	34.93	600	3.95	34.97	27.79
586	3.97	34.97	800	3.65	34.94	27.79
752	3.70	34.94	1,000	3.50	34.93	27.81
1,110	3.45	34.93				

Station 2859; Apr. 1; latitude 44°27′ N., longitude 45°54′ W.; depth 3,795 meters; dynamic height 970.974 meters

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	4.40	33.98	0	4.40	33.98	26.96
22	4.42	33.98	25	4.45	33.98	26.95
43	4.67	34.02	50	5.20	34.11	26.97
65	6.72	34.44	75	7.10	34.57	27.09
87	7.40	34.67	100	7.75	34.78	27.16
130	8.30	34.94	150	7.30	34.83	27.27
173	6.20	34.70	200	5.80	34.71	27.37
260	5.11	34.74	300	4.50	34.75	27.55
287	4.44	34.73	400	4.85	34.94	27.66
437	4.89	34.99	600	4.80	34.98	27.71
590	4.85	34.98	800	3.80	34.94	27.78
748	3.93	34.95	1,000	3.45	34.93	27.81
1,075	3.41	34.92				

Station 2860; Apr. 1; latitude 44°40′ N., longitude 46°48′ W.; depth 3,475 meters; dynamic height 970.947 meters

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	3.77	33.84	0	3.77	33.82	26.91
25	3.69	33.84	25	3.69	33.82	26.92
49	3.34	33.86	50	3.35	33.86	26.96
74	3.32	33.86	75	3.30	33.86	26.97
98	3.56	33.91	100	3.60	33.93	27.00
147	4.00	34.29	150	4.00	34.31	27.27
196	4.01	34.56	200	4.05	34.57	27.47
294	4.61	34.86	300	4.60	34.87	27.64
494	4.30	34.96	400	4.50	34.94	27.70
677	3.87	34.95	600	4.05	34.96	27.77
863	3.59	34.93	800	3.65	34.94	27.79
1,050	3.43	34.92	1,000	3.45	34.92	27.79
1,429	3.27	34.91				

Table of Oceanographic Data—Continued

STATIONS OCCUPIED IN 1939—Continued

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
Station 2861; Apr. 1; latitude 44°54′ N., longitude 47°29′ W.; depth 3,365 meters; dynamic height 970.882 meters						
0	3.23	34.08	0	3.23	34.08	27.15
24	3.25	34.07	25	3.25	34.08	27.15
47	3.77	34.19	50	3.80	34.20	27.20
71	3.90	34.24	75	3.90	34.24	27.22
94	3.98	34.25	100	3.95	34.26	27.24
141	3.84	34.42	150	3.90	34.46	27.40
189	4.45	34.72	200	4.45	34.75	27.57
283	4.34	34.89	300	4.35	34.91	27.71
338	4.39	34.95	400	4.25	34.96	27.76
515	4.01	34.97	600	3.80	34.95	27.80
697	3.63	34.93	800	3.60	34.93	27.80
881	3.55	34.92	1,000	3.50	34.92	27.80
1,260	3.30	34.92				
Station 2862; Apr. 1; latitude 44°56′ N., longitude 48°02′ W.; depth 2,843 meters; dynamic height 970.875 meters						
0	2.51	33.95	0	2.51	33.95	27.11
23	2.52	33.97	25	2.50	33.96	27.12
47	2.50	33.96	50	2.50	33.96	27.12
70	2.82	34.12	75	3.25	34.19	27.23
93	4.74	34.45	100	4.60	34.46	27.31
140	3.52	34.46	150	3.75	34.52	27.45
187	4.45	34.76	200	4.40	34.80	27.60
280	4.21	34.90	300	4.15	34.91	27.72
360	4.00	34.92	400	3.90	34.92	27.76
547	3.53	34.91	600	3.50	34.91	27.79
739	3.41	34.91	800	3.35	34.91	27.80
932	3.28	34.90	1,000	3.25	34.90	27.80
1,328	3.23	34.90				
Station 2863; Apr. 1; latitude 44°58′ N., longitude 48°35′ W.; depth 1,463 meters; dynamic height 970.875 meters						
0	−0.03	33.51	0	−0.03	33.51	26.93
24	−0.04	33.52	25	−0.05	33.53	26.94
48	0.78	34.02	50	0.85	34.09	27.34
72	1.73	34.28	75	1.70	34.29	27.44
96	1.69	34.34	100	1.75	34.36	27.50
144	3.00	34.62	150	3.00	34.63	27.61
192	2.83	34.64	200	2.85	34.64	27.63
288	3.17	34.73	300	3.30	34.76	27.69
350	3.88	34.86	400	3.85	34.88	27.72
534	3.73	34.90	600	3.70	34.90	27.76
723	3.60	34.90	800	3.55	34.90	27.77
913	3.48	34.90	1,000	3.40	34.90	27.79
1,303	3.29	34.91				
Station 2864; Apr. 2; latitude 44°58′ N., longitude 49°00′ W.; depth 622 meters; dynamic height 971.092 meters						
0	−1.47	33.08	0	−1.47	33.08	26.63
25	−1.47	33.08	25	−1.47	33.08	26.63
49	−1.37	33.30	50	−1.35	33.31	26.81
74	−1.25	33.36	75	−1.25	33.36	26.85
98	−1.22	33.37	100	−1.20	33.37	26.86
147	−1.15	33.42	150	−1.15	33.42	26.91
197	−0.74	33.53	200	−0.65	33.54	26.98
295	1.15	34.11	300	1.25	34.14	27.36
375	*1.92	34.36	400	2.10	34.41	27.51
563	2.95	34.66	(600)	3.05	34.70	27.66

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
Station 2865; Apr. 2; latitude 44°59′ N., longitude 49°07′ W.; depth 174 meters; dynamic height 971.135 meters						
0	−1.39	33.08	0	−1.39	33.08	26.63
26	−1.43	33.09	25	−1.40	33.09	26.63
52	−1.51	33.14	50	−1.50	33.14	26.68
78	−1.49	33.20	75	−1.50	33.20	26.73
104	−1.42	33.28	100	−1.45	33.27	26.78
140	−1.28	33.38	150	−1.20	33.41	26.90
Station 2866; Apr. 2; latitude 44°59′ N., longitude 49°28′ W.; depth 70 meters; dynamic height 971.136 meters						
0	−1.23	33.09	0	−1.23	33.09	26.63
27	−1.23	33.13	25	−1.25	33.13	26.66
54	−1.24	33.13	50	−1.25	33.13	26.66
Station 2867; Apr. 2; latitude 45°00′ N., longitude 49°40′ W.; depth 62 meters; dynamic height 971.140 meters						
0	−0.73	33.03	0	−0.73	33.03	26.57
27	−0.73	33.03	25	−0.75	33.03	26.57
54	−0.87	33.04	50	−0.85	33.05	26.58
Station 2868; Apr. 2; latitude 44°15′ N., longitude 49°40′ W.; depth 49 meters; dynamic height 971.094 meters						
0	−0.48	33.05	0	−0.48	33.05	26.58
17	−0.52	33.06	25	−0.55	33.06	26.58
39	−0.54	33.06	(50)	−0.55	33.06	26.58
Station 2869; Apr. 2; latitude 44°09′ N., longitude 49°13′ W.; depth 88 meters; dynamic height 971.083 meters						
0	−1.24	33.08	0	−1.24	33.08	26.62
26	−1.37	33.17	25	−1.35	33.17	26.70
51	−1.31	33.33	50	−1.30	33.33	26.83
77	−1.22	33.39	75	−1.20	33.39	26.88
Station 2870; Apr. 2; latitude 44°06′ N., longitude 49°08′ W.; depth 439 meters; dynamic height 971.075 meters						
0	−1.22	33.09	0	−1.22	33.09	26.63
22	−1.43	33.14	25	−1.45	33.14	26.68
45	−1.38	33.24	50	−1.35	33.28	26.79
67	−1.23	33.45	75	−1.15	33.46	26.94
89	−1.03	33.48	100	−1.00	33.48	26.94
134	−0.99	33.51	150	−0.80	33.54	26.98
178	−0.41	33.63	200	−0.05	33.73	27.10
267	0.91	34.05	300	1.25	34.15	27.37
356	*1.64	34.28	(400)	1.90	34.37	27.50

Table of Oceanographic Data—Continued

STATIONS OCCUPIED IN 1939—Continued

Station 2871; Apr. 2; latitude 44°03′ N., longitude 48°56′ W.; depth 1,509 meters; dynamic height 970.958 meters

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	−1.27	33.20	0	−1.27	33.20	26.72
23	−1.44	33.21	25	−1.45	33.21	26.74
47	−1.52	33.24	50	−1.50	33.25	26.77
70	−1.13	33.42	75	−0.50	33.49	26.93
94	2.29	34.03	100	2.40	34.01	27.17
141	2.65	34.19	150	2.55	34.22	27.33
187	1.83	34.35	200	1.80	34.37	27.51
281	2.39	34.53	300	2.40	34.56	27.61
270	*1.90	34.45	400	2.45	34.64	27.66
405	2.49	34.64	600	3.60	34.89	27.76
542	3.33	34.88	800	3.60	34.89	27.76
674	3.67	34.90	(1,000)	3.50	34.89	27.77
942	3.52	34.88				

Station 2872; Apr. 2; latitude 43°54′ N., longitude 48°28′ W.; depth 2,149 meters; dynamic height 970.932 meters

0	3.48	33.81	0	3.48	33.81	26.91
25	3.49	33.81	25	3.49	33.81	26.91
50	3.47	33.83	50	3.47	33.83	26.92
75	3.54	33.91	75	3.54	33.91	26.98
101	3.17	34.04	100	3.20	34.04	27.12
151	4.51	34.61	150	4.50	34.61	27.44
201	4.31	34.69	200	4.30	34.69	27.53
302	4.53	34.87	300	4.55	34.87	27.65
389	3.85	34.86	400	3.80	34.86	27.72
583	3.64	34.90	600	3.65	34.90	27.76
777	3.49	34.89	800	3.50	34.89	27.77
974	3.39	34.90	1,000	3.40	34.90	27.79
1,370	3.31	34.89				

Station 2873; Apr. 2–3; latitude 43°43′ N., longitude 47°49′ W.; depth 3,667 meters; dynamic height 970.935 meters

0	4.32	33.83	0	4.32	33.83	26.84
24	4.32	33.85	25	4.30	33.85	26.86
48	2.83	33.72	50	2.85	33.72	26.90
71	4.55	34.11	75	4.50	34.12	27.06
95	4.14	34.18	100	4.05	34.20	27.17
143	3.37	34.38	150	3.30	34.40	27.40
191	3.18	34.54	200	3.30	34.57	27.54
286	4.57	34.87	300	4.55	34.87	27.65
396	4.13	34.90	400	4.10	34.90	27.72
593	3.81	34.91	600	3.80	34.91	27.76
790	3.65	34.90	800	3.65	34.90	27.76
989	3.60	34.92	1,000	3.60	34.92	27.79
1,387	3.29	34.89				

Station 2874; Apr. 3; latitude 43°27′ N., longitude 46°52′ W.; depth 3,850 meters; dynamic height 971.067 meters

0	12.94	35.51	0	12.94	35.51	26.82
25	12.10	35.33	25	12.10	35.33	26.84
50	10.85	35.11	50	10.85	35.11	26.91
75	8.78	34.78	75	8.78	34.78	27.00
99	8.66	34.72	100	8.65	34.75	27.00
149	10.20	35.17	150	10.15	35.17	27.08
199	8.16	34.79	200	8.10	34.79	27.11
298	6.51	34.83	300	6.45	34.83	27.38
394	5.18	34.80	400	5.15	34.80	27.52
594	4.58	34.94	600	4.55	34.94	27.70
796	4.15	34.96	800	4.15	34.96	27.76
992	3.84	34.93	1,000	3.85	34.93	27.76
1,382	3.40	34.93				

Station 2875; Apr. 3; latitude 43°24′ N., longitude 45°59′ W.; depth 4,536 meters; dynamic height 971.245 meters

0	12.96	35.46	0	12.96	35.46	26.78
25	12.81	35.46	25	12.81	35.46	26.81
50	12.80	35.47	50	12.80	35.46	26.81
75	12.82	35.46	75	12.82	35.46	26.81
100	12.86		100	12.86	35.46	26.80
150	12.84	35.46	150	12.84	35.46	26.81
199	12.83	35.46	200	12.80	35.46	26.81
299	*11.68	35.49	300	11.65	35.49	27.05
395	9.32	35.16	400	9.20	35.15	27.22
596	5.91	34.96	600	5.90	34.96	27.56
801	5.29	35.06	800	5.30	35.06	27.71
997	4.88	35.04	1,000	4.65	35.04	27.77
1,386	3.83	34.96				

Station 2876; Apr. 3; latitude 42°51′ N., longitude 46°09′ W.; depth 4,564 meters; dynamic height 971.318 meters

0	13.39	35.48	0	13.39	35.48	26.70
24	13.40	35.49	25	13.40	35.49	26.71
73	13.43	35.50	50	13.40	35.50	26.72
97	13.36	35.50	75	13.40	35.50	26.72
146	13.09	35.46	100	13.35	35.50	26.73
195	12.95	35.46	150	13.05	35.46	26.76
292	12.02	35.46	200	12.90	35.46	26.79
357	11.04	35.36	300	11.95	35.46	26.98
541	7.88	35.03	400	10.25	35.24	27.11
729	5.91	35.02	600	7.10	35.03	27.44
919	4.84	35.03	800	5.45	35.02	27.66
1,310	3.81	34.95	1,000	4.50	35.02	27.77

Station 2877; Apr. 3; latitude 42°26′ N., longitude 46°21′ W.; depth 4,481 meters; dynamic height 971.512 meters

0	15.94	36.23	0	15.94	36.23	26.72
24	15.95	36.22	25	15.95	36.22	26.71
49	15.97	36.22	50	15.95	36.22	26.71
73	16.00	36.22	75	15.95	36.22	26.71
98	15.99	36.22	100	15.95	36.22	26.71
146	16.02	36.22	150	16.00	36.22	26.70
195	16.00	36.22	200	15.95	36.22	26.71
292	*15.94	36.22	300	15.95	36.22	26.71
368		36.21	400	15.45	36.12	26.75
552	11.65	35.47	600	10.25	35.27	27.14
736	6.59	34.87	800	5.70	34.89	27.52
921	4.98	34.94	1,000	4.80	34.96	27.69
1,293	4.31	35.01				

Station 2878; Apr. 4; latitude 42°34′ N., longitude 47°04′ W.; depth 3,887 meters; dynamic height 971.186 meters

0	15.55	35.92	0	15.55	35.92	26.58
24	15.57	35.92	25	15.55	35.92	26.58
48	15.32	35.84	50	15.20	35.83	26.58
71	14.64	35.71	75	14.55	35.71	26.63
95	14.40	35.72	100	14.30	35.72	26.70
143	13.63	35.64	150	13.50	35.62	26.79
190	12.60	35.46	200	12.35	35.44	26.88
285	10.92	35.34	300	10.50	35.30	27.12
368	7.51	34.94	400	6.60	34.94	27.44
553	5.16	34.94	600	4.95	34.95	27.66
741	4.53	34.97	800	4.35	34.97	27.75
924	4.08	34.96	1,000	3.95	34.96	27.78
1,294	3.65	34.95				

Table of Oceanographic Data—Continued

STATIONS OCCUPIED IN 1939—Continued

Station 2879; Apr. 4; latitude 42°51′ N., longitude 47°47′ W.; depth 3,521 meters; dynamic height 970.934 meters

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	3.95	33.68	0	3.95	33.68	26.77
24	3.16	33.82	25	3.15	33.83	26.95
49	6.44	34.52	50	6.45	34.52	27.14
73	4.92	34.34	75	4.90	34.33	27.17
97	4.16	34.30	100	4.05	34.30	27.25
146	3.39	34.44	150	3.40	34.45	27.43
195	3.89	34.60	200	3.95	34.61	27.50
292	4.63	34.85	300	4.60	34.85	27.62
385	4.35	34.88	400	4.40	34.92	27.70
533	4.53	35.01	600	4.45	34.99	27.75
712	4.15	34.97	800	4.05	34.96	27.77
914	3.94	34.96	1,000	3.90	34.96	27.79
1,346	3.48	34.92				

Station 2880; Apr. 4; latitude 43°08′ N., longitude 48°27.5′ W.; depth 2,698 meters; dynamic height 970.902 meters

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	2.82	33.69	0	2.82	33.69	26.88
24	2.82	33.72	25	2.80	33.72	26.91
48	2.50	33.70	50	2.45	33.70	26.91
73	1.97	33.88	75	1.95	33.90	27.11
97	3.02	34.35	100	3.30	34.41	27.41
145	4.40	34.69	150	4.40	34.70	27.52
193	4.46	34.77	200	4.45	34.78	27.58
290	4.26	34.93	300	4.20	34.93	27.73
366	3.98	34.90	400	3.85	34.89	27.73
553	3.67	34.88	600	3.65	34.89	27.75
743	3.76	34.93	800	3.70	34.93	27.78
935	3.57	34.92	1,000	3.50	34.92	27.80
1,323	3.39	34.90				

Station 2881; Apr. 4; latitude 43°22′ N.; longitude 49°04′ W.; depth 1,463 meters; dynamic height 970.983 meters

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	−1.34	33.14	0	−1.34	33.14	26.68
24	−1.60	33.16	25	−1.60	33.16	26.70
49	−1.70	33.26	50	−1.70	33.27	26.79
73	−1.52	33.44	75	−1.50	33.46	26.95
97	0.28	33.79	100	0.75	33.87	27.18
146	3.70	34.33	150	3.65	34.33	27.31
194	1.58	34.28	200	1.60	34.29	27.45
291	2.52	34.52	300	2.60	34.54	27.57
367	3.05	34.69	400	3.25	34.72	27.66
548	3.73	34.82	600	3.75	34.84	27.70
727	3.71	34.88	800	3.65	34.89	27.75
911	3.59	34.90	1,000	3.55	34.90	27.77
1,279	3.41	34.89				

Station 2882; Apr. 4–5; latitude 42°37′ N., longitude 49°08′ W.; depth 2,424 meters; dynamic height 970.919 meters

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	1.83	33.45	0	1.83	33.45	26.77
25	2.06	33.52	25	2.06	33.52	26.82
50	1.16	33.74	50	1.16	33.74	27.04
75	2.57	34.17	75	2.57	34.17	27.29
100	3.15	34.34	100	3.15	34.34	27.36
150	3.90	34.56	150	3.90	34.56	27.47
201	4.86	34.82	200	4.85	34.81	27.56
301	4.80	34.91	300	4.80	34.91	27.65
398	4.52	34.96	400	4.50	34.96	27.72
595	4.05	34.93	600	4.05	34.93	27.74
791	3.78	34.94	800	3.75	34.94	27.78
989	3.60	34.92	1,000	3.60	34.92	27.79
1,384	3.37	34.90				

Station 2883; Apr. 5; latitude 42°07′ N., longitude 48°21′ W.; depth 3,292 meters; dynamic height 970.963 meters

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	3.58	33.56	0	3.58	33.56	26.71
25	4.07	33.84	25	4.07	33.84	26.87
50	5.65	34.18	50	5.65	34.18	26.97
75	7.60	34.65	75	7.60	34.65	27.08
99	6.32	34.50	100	6.30	34.50	27.14
149	4.99	34.57	150	4.95	34.57	27.36
199	4.22	34.56	200	4.20	34.56	27.44
298	4.38	34.78	300	4.40	34.79	27.59
385	4.59	34.92	400	4.60	34.93	27.68
577	4.33	34.96	600	4.30	34.96	27.74
770	4.03	34.96	800	3.95	34.95	27.77
964	3.61	34.91	1,000	3.60	34.91	27.78
1,356	3.43	34.91				

Station 2884; Apr. 5; latitude 41°38′ N., longitude 47°38′ W.; depth 3,996 meters; dynamic height 971.101 meters

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	13.80	35.49	0	13.80	35.49	26.62
24	13.36	35.52	25	13.35	35.52	26.74
48	13.02	35.47	50	12.95	35.45	26.77
72	12.50	35.36	75	12.40	35.35	26.80
96	11.73	35.24	100	11.65	35.23	26.85
144	11.21	35.19	150	11.20	35.20	26.91
193	11.50	35.43	200	11.35	35.41	27.05
289	7.34	34.82	300	6.85	34.78	27.28
285	7.57	34.88	400	3.75	34.61	27.52
421	3.51	34.60	600	4.05	34.88	27.70
553	4.12	34.87	800	3.80	34.91	27.76
702	3.79	34.89	1,000	3.90	34.96	27.79
1,013	3.91	34.96				

Station 2885; Apr. 5; latitude 41°10′ N., longitude 48°08′ W.; depth 3,347 meters; dynamic height 970.968 meters

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	2.44	33.31	0	2.44	33.31	26.60
23	4.65	33.80	25	4.90	33.83	26.78
45	6.43	34.17	50	6.00	34.13	26.88
68	2.12	33.68	75	0.95	33.66	26.99
91	0.07	33.65	100	0.15	33.69	27.06
136	0.63	33.96	150	0.85	34.04	27.30
183	1.24	34.20	200	1.75	34.30	27.45
272	4.35	34.74	300	4.30	34.81	27.63
339	4.29	34.87	400	4.25	34.88	27.68
511	4.20	34.90	600	4.10	34.93	27.74
684	3.99	34.95	800	3.85	34.93	27.76
866	3.74	34.93	1,000	3.60	34.93	27.79
1,244	3.49	34.93				

Station 2886; Apr. 6; latitude 41°48′ N., longitude 49°20′ W.; depth 2,908 meters; dynamic height 970.913 meters

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	−0.37	33.04	0	−0.37	33.04	26.56
25	−0.10	33.30	25	−0.10	33.30	26.75
49	−0.27	33.64	50	−0.25	33.66	27.06
74	0.70	34.00	75	0.75	34.02	27.30
99	3.29	34.42	100	3.35	34.43	27.41
148	4.10	34.65	150	4.15	34.66	27.52
197	4.53	34.77	200	4.50	34.77	27.57
296	4.36	34.87	300	4.35	34.87	27.67
373	4.22	34.91	400	4.20	34.91	27.72
562	4.00	34.93	600	3.95	34.93	27.75
754	3.80	34.94	800	3.75	34.94	27.78
947	3.62	34.93	1,000	3.60	34.93	27.79
1,338	3.38	34.91				

Table of Oceanographic Data—Continued

STATIONS OCCUPIED IN 1939—Continued

Station 2887; Apr. 6; latitude 40°56′ N., longitude 49°53′ W.; depth 3,566 meters; dynamic height 971.625 meters

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	17.86	36.39	0	17.86	36.39	26.39
24	17.92	36.40	25	17.90	36.40	26.39
48	17.96	36.40	50	17.95	36.40	26.38
72	17.98	36.41	75	17.95	36.41	26.38
96	17.91	36.41	100	17.90	36.41	26.39
144	17.78	36.43	150	17.75	36.43	26.45
192	17.68	36.45	200	17.65	36.45	26.49
288	17.14	36.35	300	17.00	36.32	26.54
259	17.40	36.41	400	15.65	36.11	26.70
381		36.16	600	11.25	35.40	27.06
498	*13.77	35.80	800	5.70	34.83	27.47
610	10.96	35.37	(1,000)	4.45	34.93	27.70
819	5.42	34.82				

Station 2888; Apr. 6; latitude 41°23′ N., longitude 49°42′ W.; depth 2,908 meters; dynamic height 971.305 meters

0	14.67	35.67	0	14.67	35.67	26.58
23	14.71	35.66	25	14.70	35.66	26.56
46	14.75	35.68	50	14.75	35.67	26.56
70	14.34	35.60	75	14.15	35.54	26.59
92	13.14	35.40	100	13.25	35.43	26.69
139	14.32	35.58	150	13.90	35.60	26.69
185	11.91	35.20	200	11.85	35.23	26.81
277	11.75	35.46	300	11.75	35.45	27.01
275	12.05	35.48	400	10.60	35.32	27.12
467	9.49	35.21	600	6.80	35.00	27.47
695	5.45	34.94	800	4.95	35.02	27.72
795	4.99	35.02	(1,000)	4.00	34.95	27.77
906	4.32	34.97				

Station 2889; Apr. 7; latitude 42°04′ N., longitude 49°33′ W.; depth 3,182 meters; dynamic height 970.918 meters.

0	0.38	33.30	0	0.38	33.30	26.73
20	0.40	33.30	25	0.40	33.33	26.76
40	0.45	33.44	50	0.40	33.54	26.93
59	0.34	33.62	75	0.50	33.80	27.13
78	0.56	33.82	100	1.60	34.08	27.28
118	2.20	34.26	150	2.15	34.43	27.52
158	2.12	34.45	200	2.55	34.59	27.62
236	2.98	34.68	300	3.75	34.79	27.66
307	3.77	34.80	400	3.85	34.86	27.71
492	3.84	34.89	600	3.80	34.90	27.75
697	3.71	34.90	800	3.70	34.92	27.78
880	3.67	34.94	1,000	3.55	34.93	27.79
1,258	3.30	34.89				

Station 2890; Apr. 7; latitude 42°24′ N., longitude 49°33′ W.; depth 2,807 meters; dynamic height 970.913 meters.

0	−0.74	33.14	0	−0.74	33.14	26.66
23	−0.74	33.17	25	−0.75	33.19	26.70
45	−0.84	33.44	50	−0.75	33.54	26.99
68	0.49	33.95	75	0.70	34.03	27.30
90	0.99	34.16	100	1.10	34.21	27.43
135	1.52	34.30	150	1.75	34.36	27.50
181	2.19	34.48	200	2.35	34.52	27.58
271	2.89	34.66	300	3.25	34.72	27.66
361	4.00	34.86	400	3.95	34.87	27.71
546	3.72	34.89	600	3.65	34.89	27.75
925	3.40		800	3.50	34.89	27.77
1,318	3.30	34.90	1,000	3.40	34.90	27.79

Station 2891; Apr. 7; latitude 42°52′ N., longitude 49°33′ W.; depth 1,628 meters; dynamic height 970.922 meters.

0	−1.21	33.29	0	−1.21	33.29	26.79
24	−1.27	33.34	25	−1.25	33.36	26.85
48	1.68	33.90	50	1.90	33.94	27.15
72	3.04	34.12	75	3.15	34.09	27.16
96	3.63	34.23	100	3.65	34.25	27.25
144	3.90	34.52	150	3.85	34.52	27.44
193	2.65	34.49	200	2.65	34.49	27.53
289	2.74	34.64	300	2.95	34.70	27.67
318	3.52	34.77	400	3.80	34.83	27.69
480	3.84	34.87	600	3.75	34.91	27.76
644	3.77	34.92	800	3.55	34.90	27.77
823	3.55	34.88	1,000	3.50	34.90	27.78
1,206	3.48	34.90				

Station 2892; Apr. 7; latitude 43°04′ N., longitude 49°36′ W.; depth 613 meters; dynamic height 971.024 meters.

0	−1.22	33.42	0	−1.22	33.42	26.91
25	−1.26	33.28	25	−1.26	33.28	26.78
49	−1.33	33.30	50	−1.35	33.30	26.80
74	−1.53	33.34	75	−1.55	33.34	26.85
98	−1.59	33.43	100	−1.50	33.45	26.94
147	1.08	33.93	150	1.10	33.95	27.22
197	1.04	34.17	200	1.10	34.18	27.40
295	2.07	34.40	300	2.10	34.41	27.51
388	*2.31	34.51	400	2.35	34.52	27.58
582	2.97	34.67	600	3.00	34.68	27.65

Station 2893; Apr. 7; latitude 43°07′ N., longitude 49°41′ W.; depth 274 meters; dynamic height 971.075 meters.

0	−0.89	33.11	0	−0.89	33.11	26.64
25	−0.92	33.13	25	−0.92	33.13	26.66
50	−0.94	33.14	50	−0.94	33.14	26.67
75	−1.32	33.24	75	−1.32	33.24	26.76
100	−1.46	33.32	100	−1.46	33.32	26.82
150	−0.67	33.56	150	−0.67	33.56	27.00
200	0.46	33.90	200	0.46	33.90	27.21

Station 2894; Apr. 7; latitude 43°11′ N., longitude 49°49′ W.; depth 88 meters; dynamic height 971.093 meters.

0	−0.73	33.13	0	−0.73	33.13	26.65
26	−0.78	33.12	25	−0.75	33.12	26.64
52	−0.88	33.14	50	−0.85	33.14	26.66
78	−1.10	33.16	75	−1.05	33.16	26.68

Station 2895; Apr. 7; latitude 43°21′ N., longitude 50°10′ W.; depth 66 meters; dynamic height 971.097 meters.

0	0.46	33.17	0	0.46	33.17	26.63
26	0.49	33.16	25	0.50	33.16	26.61
53	0.42	33.17	50	0.45	33.17	26.63

Table of Oceanographic Data—Continued

STATIONS OCCUPIED IN 1939—Continued

Station 2896; Apr. 7; latitude 43°09′ N., longitude 50°27′ W.; depth 88 meters; dynamic height 971.100 meters.

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	0.63	33.14	0	0.63	33.14	26.60
26	0.64	33.14	25	0.65	33.14	26.60
53	0.45	33.15	50	0.50	33.15	26.60
79	−0.16	33.22	75	−0.05	33.21	26.69

Station 2897; Apr. 7–8; latitude 42°57′ N., longitude 50°47′ W.; depth 622 meters; dynamic height 971.110 meters.

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	−0.48	33.11	0	−0.48	33.11	26.62
25	−0.57	33.13	25	−0.57	33.13	26.64
50	−1.31	33.20	50	−1.31	33.20	26.72
75	−1.42	33.27	75	−1.42	33.27	26.78
101	−1.41	33.29	100	−1.40	33.29	26.79
151	−1.32	33.35	150	−1.35	33.35	26.84
201	−0.98	33.48	200	−1.00	33.48	26.94
302	0.47	33.87	300	0.40	33.86	27.19
394	*2.40	34.51	400	2.50	34.53	27.57
591	3.49	34.78	600	3.45	34.79	27.69

Station 2898; Apr. 8; latitude 42°51′ N., longitude 50° 53′ W.; depth 1,463 meters; dynamic height 971.110 meters.

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	−0.88	33.13	0	−0.88	33.13	26.66
25	−0.90	33.14	25	−0.90	33.15	26.67
50	−1.22	33.16	50	−1.22	33.16	26.69
75	−1.29	33.27	75	−1.29	33.27	26.78
100	−1.25	33.35	100	−1.25	33.35	26.85
150	−0.83	33.55	150	−0.83	33.55	26.99
200	−0.46	33.67	200	−0.46	33.67	27.08
300	0.40	33.91	300	0.40	33.91	27.22
355	*1.17	34.13	400	1.75	34.30	27.45
537	3.00	34.65	600	3.35	34.74	27.66
722	3.75	34.85	800	3.70	34.88	27.74
909	3.66	34.89	1,000	3.60	34.89	27.76
1,291	3.47	34.89				

Station 2899; Apr. 8; latitude 42°29.5′ N., longitude 51°27′ W.; depth 2,880 meters; dynamic height 971.013 meters.

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	5.46	33.78	0	5.46	33.78	26.68
23	6.75	34.15	25	6.70	34.15	26.81
45	5.96	34.05	50	5.70	34.04	26.85
68	5.01	34.03	75	5.00	34.05	26.94
90	5.08	34.17	100	5.85	34.31	27.05
135	8.58	34.93	150	8.80	35.04	27.20
180		35.13	200	8.45	35.07	27.28
270	5.81	34.82	300	5.45	34.86	27.52
306	5.39	34.87	400	4.90	34.92	27.65
466	4.70	34.94	600	4.50	34.98	27.73
631	4.46	34.98	800	3.80	34.90	27.75
805	3.80	34.90	1,000	3.65	34.91	27.77
1,170	3.59	34.92				

Station 2900; Apr. 8; latitude 42°07′ N., longitude 52° 00′ W.; depth 2,640 meters; dynamic height 971.278 meters.

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	15.97	36.06	0	15.97	36.06	26.58
24	15.99	36.06	25	16.00	36.06	26.58
48	16.01	36.06	50	16.00	36.06	26.58
72	16.03	36.06	75	16.00	36.06	26.58
95	16.01	36.06	100	16.00	36.06	26.58
144	16.00	36.07	150	15.95	36.07	26.59
191	15.14	35.99	200	14.95	35.96	26.74
286	12.76	35.62	300	12.35	35.56	26.97
327	11.68	35.47	400	9.50	35.22	27.23
495	7.06	35.01	600	5.50	34.96	27.60
667	4.99	34.95	800	4.50	34.97	27.73
849	4.37	34.97	1,000	4.10	34.97	27.78
1,229	3.87	34.965				

Station 2901; Apr. 8; latitude 42°00′ N., longitude 50° 46′ W.; depth 3,191 meters; dynamic height 971.117 meters.

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	12.21	35.25	0	12.21	35.25	26.76
26	12.25	35.25	25	12.25	35.25	26.76
51	12.30	35.24	50	12.30	35.25	26.74
77	12.31	35.25	75	12.30	35.25	26.74
102	11.78	35.15	100	11.80	35.16	26.77
155	12.12	35.50	150	12.10	35.50	26.98
206	10.52	35.30	200	10.75	35.32	27.09
308	8.41	35.08	300	8.45	35.08	27.28
332	7.74	35.06	400	5.55	34.94	27.58
502	2.56	34.54	600	3.80	34.76	27.63
675	4.25	34.89	800	4.40	34.96	27.72
864	4.35	34.97	1,000	4.00	34.96	27.77
1,265	3.63	34.93				

Station 2902; Apr. 23; latitude 46°23′ N., longitude 48° 48′ W.; depth 66 meters; dynamic height 971.093 meters.

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	0.14	32.70	0	0.14	32.70	26.26
26	−0.13	32.78	25	−0.15	32.78	26.35
53	−0.30	32.80	50	−0.30	32.80	26.37

Station 2903; Apr. 23; latitude 46°12′ N., longitude 48°32′ W.; depth 88 meters; dynamic height 971.088 meters.

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	0.45	32.76	0	0.45	32.76	26.30
26	−0.28	32.86	25	−0.25	32.86	26.41
52	−0.80	32.97	50	−0.75	32.96	26.51
78	−0.90	33.01	75	−0.90	33.01	26.56

Station 2904; Apr. 23; latitude 45°58′ N., longitude 48°13′ W.; depth 112 meters; dynamic height 971.075 meters

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	−0.85	32.95	0	−0.85	32.95	26.50
26	−1.39	33.04	25	−1.40	33.04	26.60
52	−1.54	33.07	50	−1.55	33.07	26.63
78	−1.54	33.11	75	−1.55	33.11	26.66
104	−1.05	33.16	100	−1.15	33.15	26.68

Table of Oceanographic Data—Continued

STATIONS OCCUPIED IN 1939—Continued

Station 2905; Apr. 23; latitude 45°52′ N., longitude 48°05′ W.; depth 167 meters; dynamic height 971.068 meters

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	−0.78	33.02	0	−0.78	33.02	26.56
26	−1.35	33.06	25	−1.35	33.06	26.61
51	−1.56	33.13	50	−1.55	33.13	26.67
77	−1.45	33.20	75	−1.45	33.20	26.73
103	−1.32	33.30	100	−1.35	33.29	26.79
154	−1.34	33.27	150	−1.35	33.30	26.80

Station 2906; Apr. 23; latitude 45°48′ N., longitude 47°57′ W.; depth 631 meters; dynamic height 971.021 meters

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	−1.27	32.96	0	−1.27	32.96	26.53
25	−1.68	33.12	25	−1.68	33.12	26.67
50	−1.63	33.21	50	−1.63	33.21	26.74
75	−1.29	33.36	75	−1.29	33.36	26.85
100	−0.75	33.49	100	−0.75	33.49	26.94
150	0.04	33.69	150	0.04	33.69	27.07
201	0.86	33.94	200	0.85	33.93	27.21
301	2.40	34.46	300	2.35	34.45	27.52
394	2.83	34.64	400	2.85	34.65	27.64
589	3.73	34.89	600	3.75	34.89	27.74

Station 2907; Apr. 23; latitude 45°43.5′ N., longitude 47°53′ W.; depth 1,097 meters; dynamic height 970.950 meters

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	−1.28	32.86	0	−1.28	32.86	26.45
25	−1.38	33.13	25	−1.38	33.13	26.67
50	−0.77	33.47	50	−0.77	33.47	26.93
75	−0.15	33.68	75	−0.15	33.68	27.07
100	0.42	33.88	100	0.42	33.88	27.20
150	1.69	34.29	150	1.69	34.29	27.44
200	2.12	34.44	200	2.12	34.44	27.53
300	2.58	34.59	300	2.58	34.59	27.62
391	2.65	34.70	400	2.65	34.71	27.71
587	3.74	34.84	600	3.75	34.85	27.71
782	3.58	34.89	800	3.55	34.89	27.76
978	3.52	34.90	1,000	3.50	34.90	27.78

Station 2908; Apr. 23; latitude 45°36′ N., longitude 47°48′ W.; depth 1,490 meters; dynamic height 970.873 meters

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	0.31	33.47	0	0.31	33.47	26.88
25	0.02	33.54	25	0.02	33.54	26.95
50	0.29	33.78	50	0.29	33.78	27.12
76	1.53	34.23	75	1.50	34.22	27.41
101	1.83	34.35	100	1.80	34.34	27.48
151	2.39	34.54	150	2.40	34.54	27.59
202	2.51	34.61	200	2.50	34.61	27.64
303	3.04	34.73	300	3.00	34.73	27.69
394	3.72	34.89	400	3.70	34.89	27.75
593	3.58	34.91	600	3.55	34.91	27.78
792	3.47	34.89	800	3.45	34.90	27.78
989	3.38	34.89	1,000	3.35	34.89	27.78
1,383	3.30	34.89				

Station 2909; Apr. 24; latitude 45°18′ N., longitude 47°18′ W.; depth 2,761 meters; dynamic height 970.954 meters

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	1.39	33.50	0	1.39	33.50	26.84
25	2.61	33.84	25	2.61	33.84	27.01
50	3.71	34.12	50	3.71	34.12	27.14
75	5.01	34.42	75	5.01	34.42	27.24
100	5.35	34.46	100	5.35	34.47	27.24
150	5.59	34.53	150	5.59	34.53	27.25
199	4.55	34.46	200	4.55	34.46	27.32
299	4.83	34.80	300	4.80	34.80	27.56
373	4.02	34.84	400	4.00	34.86	27.70
562	4.27	34.96	600	4.20	34.96	27.76
754	3.69	34.91	800	3.60	34.90	27.77
951	3.50	34.90	1,000	3.45	34.90	27.78
1,356	3.29	34.89				

Station 2910; Apr. 24; latitude 45°16.5′ N., longitude 46°26′ W.; depth 3,356 meters; dynamic height 970.886 meters

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	2.34	33.87	0	2.34	33.87	27.06
25	2.01	34.02	25	2.01	34.02	27.21
49	1.65	34.06	50	1.65	34.06	27.27
74	2.53	34.18	75	2.55	34.18	27.29
98	3.28	34.37	100	3.30	34.38	27.38
147	3.86	34.56	150	3.90	34.57	27.48
196	4.09	34.73	200	4.10	34.74	27.59
294	3.91	34.85	300	3.90	34.85	27.70
375	4.01	34.90	400	4.00	34.90	27.73
566	3.68	34.89	600	3.65	34.89	27.75
758	3.55	34.90	800	3.50	34.90	27.78
953	3.35	34.89	(1,000)	3.30	34.89	27.79

Station 2911; Apr. 24; latitude 45°15′ N., longitude 45°33′ W.; depth 3,493 meters; dynamic height 970.945 meters

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	6.22	34.10	0	6.22	34.10	26.84
25	4.28	34.06	25	4.28	34.06	27.03
50	3.59	34.02	50	3.59	34.02	27.07
75	3.84	34.04	75	3.84	34.05	27.07
101	4.08	34.14	100	4.05	34.13	27.11
151	4.41	34.41	150	4.40	34.41	27.30
201	4.41	34.61	200	4.40	34.61	27.46
302	5.00	34.90	300	4.95	34.90	27.62
394	4.58	34.93	400	4.55	34.93	27.69
590	3.89	34.92	600	3.85	34.92	27.76
786	3.77	34.92	800	3.75	34.92	27.77
983	3.56	34.92	1,000	3.50	34.92	27.80
1,378	3.38	34.91				

Station 2912; Apr. 24; latitude 44°51′ N., longitude 45°45′ W.; depth 3,566 meters; dynamic height 970.926 meters

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	3.52	33.88	0	3.52	33.88	26.96
25	2.48	33.91	25	2.48	33.91	27.08
51	3.57	34.08	50	3.55	34.06	27.11
76	4.32	34.25	75	4.30	34.25	27.18
101	4.28	34.31	100	4.30	34.31	27.23
152	4.43	34.49	150	4.40	34.48	27.35
202	4.84	34.69	200	4.85	34.68	27.46
304	4.22	34.81	300	4.25	34.81	27.63
391	4.48	34.94	400	4.45	34.94	27.71
587	4.11	34.95	600	4.10	34.95	27.76
782	3.75	34.94	800	3.70	34.94	27.79
979	3.56	34.93	1,000	3.55	34.93	27.79
1,375	3.31	34.90				

Table of Oceanographic Data—Continued

STATIONS OCCUPIED IN 1939—Continued

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
Station 2913; Apr. 24; latitude 44°27′ N., longitude 45°56′ W.; depth 3,658 meters; dynamic height 970.959 meters						
0	4.54	33.67	0	4.54	33.67	26.70
25	3.72	33.80	25	3.72	33.80	26.88
50	3.67	33.84	50	3.67	33.84	26.91
75	3.13	33.92	75	3.13	33.92	27.04
101	1.70	33.88	100	1.75	33.88	27.11
151	3.28	34.37	150	3.25	34.36	27.37
201	3.90	34.58	200	3.90	34.58	27.48
302	4.61	34.84	300	4.60	34.83	27.60
397	4.94	34.98	400	4.95	34.98	27.68
595	4.21	34.95	600	4.20	34.95	27.75
793	3.86	34.94	800	3.85	34.94	27.77
990	3.69	34.925	1,000	3.65	34.93	27.78
1,382	3.43	34.925				
Station 2914; Apr. 25; latitude 44°37′ N., longitude 46°53′ W.; depth 3,667 meters; dynamic height 970.979 meters						
0	4.05	33.82	0	4.05	33.82	26.86
24	3.35	33.80	25	3.35	33.80	26.91
48	3.78	33.91	50	3.80	33.92	26.97
72	3.85	33.94	75	3.80	33.94	26.98
96	3.56	33.96	100	3.70	34.02	27.06
144	7.17	34.78	150	7.05	34.78	27.26
193	6.03	34.70	200	5.95	34.70	27.34
289	4.60	34.74	300	4.65	34.78	27.56
336	4.83	34.90	400	4.75	34.94	27.67
511	4.48	34.96	600	4.15	34.95	27.75
690	3.89	34.94	800	3.75	34.93	27.77
891	3.72	34.925	1,000	3.65	34.92	27.78
1,329	3.45	34.91				
Station 2915; Apr. 25; latitude 44°47′ N., longitude 47°48′ W.; depth 3,228 meters; dynamic height 970.906 meters						
0	3.26	33.77	0	3.26	33.77	26.90
26	3.36	33.86	25	3.35	33.86	26.96
51	2.90	33.92	50	2.90	33.92	27.06
77		34.13	75	2.85	34.12	27.22
102	2.94	34.21	100	2.90	34.20	27.28
153	3.95	34.60	150	3.90	34.58	27.48
205	4.18	34.74	200	4.15	34.73	27.57
307	4.26	34.88	300	4.25	34.87	27.68
394	4.11	34.91	400	4.10	34.91	27.73
591	3.76	34.90	600	3.75	34.90	27.75
787	3.59	34.93	800	3.60	34.93	27.79
984	3.51	34.91	1,000	3.50	34.92	27.80
1,379	3.37	34.925				
Station 2916; Apr. 25; latitude 44°51′ N., longitude 48°22′ W.; depth 1,994 meters; dynamic height 970.914 meters						
0	3.31	33.81	0	3.31	33.81	26.93
25	2.67	33.76	25	2.67	33.76	26.95
50	2.71	33.87	50	2.71	33.87	27.03
75	3.82	34.10	75	3.82	34.10	27.11
100	3.15	34.15	100	3.15	34.15	27.21
150	3.70	34.46	150	3.70	34.46	27.41
199	4.26	34.67	200	4.25	34.67	27.52
299	4.20	34.86	300	4.20	34.86	27.68
380	4.05	34.92	400	4.00	34.93	27.75
572	3.89	34.93	600	3.85	34.93	27.76
766	3.47	34.90	800	3.45	34.90	27.78
961	3.45	34.91	1,000	3.40	34.91	27.80
1,355	3.29	34.90				

Observed values			Scaled values			
Depth, meters	Temperature C°.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
Station 2917; Apr. 25; latitude 44°52.5′ N., longitude 48°39.5′ W.; depth 1,463 meters; dynamic height 970.947 meters						
0	−0.52	33.10	0	−0.52	33.10	26.61
25	−0.18	33.35	25	−0.18	33.35	26.80
50	−0.72	33.46	50	−0.72	33.46	26.92
75	−0.38	33.60	75	−0.38	33.60	27.02
101	1.27	33.82	100	1.25	33.81	27.09
151	1.72	34.16	150	1.70	34.15	27.33
201	2.62	34.46	200	2.60	34.45	27.50
302	2.63	34.63	300	2.65	34.62	27.64
371	3.25	34.75	400	3.40	34.79	27.70
559	3.76	34.90	600	3.75	34.90	27.75
749	3.54	34.90	800	3.50	34.90	27.78
942	3.46	34.89	1,000	3.45	34.90	27.78
1,336	3.38	34.89				
Station 2918; Apr. 25; latitude 44°53′ N., longitude 48°57′ W.; depth 622 meters; dynamic height 971.065 meters						
0	−0.89	33.08	0	−0.89	33.08	26.61
24	−0.90	33.08	25	−0.90	33.08	26.61
48	−1.51	33.12	50	−1.50	33.13	26.67
71	−1.49	33.25	75	−1.50	33.26	26.78
95	−1.44	33.30	100	−1.45	33.31	26.81
143	−1.31	33.34	150	−1.25	33.36	26.85
190	−0.26	33.57	200	−0.05	33.63	27.02
285	1.20	34.11	300	1.35	34.19	27.39
344	*1.84	34.38	400	2.40	34.57	27.62
516	3.64	34.85	(600)	3.70	34.89	27.75
Station 2919; Apr. 25; latitude 44°53′ N., longitude 49°07′ W.; depth 165 to 137 meters; dynamic height 971.096 meters						
0	−0.62	33.08	0	−0.62	33.08	26.60
16	−0.85	33.07	25	−0.95	33.07	26.61
41	−1.09	33.10	50	−1.25	33.13	26.66
67	−1.55	33.19	75	−1.55	33.20	26.73
93	−1.51	33.21	100	−1.50	33.22	26.75
145	−1.13	33.29	150	−1.10	33.30	26.79
Station 2920; Apr. 26; latitude 44°54′ N., longitude 49°28′ W.; depth 70 meters; dynamic height 971.104 meters						
0	−0.01	33.02	0	−0.01	33.02	26.53
26	−0.13	33.02	25	−0.10	33.02	26.53
53	−0.79	33.05	50	−0.65	33.05	26.58
Station 2921; Apr. 26; latitude 44°54′ N., longitude 49°42′ W.; depth 64 meters; dynamic height 971.105 meters						
0	0.20	32.99	0	0.20	32.99	26.50
27	−0.15	33.02	25	−0.15	33.02	26.54
54	−0.44	33.02	50	−0.40	33.02	26.55
Station 2922; Apr. 26; latitude 44°16.5′ N., longitude 49°29′ W.; depth 46 meters; dynamic height 971.051 meters						
0	0.09	33.06	0	0.09	33.06	26.56
21	0.06	33.05	25	0.00	33.05	26.56
37	−0.10	33.04				

Table of Oceanographic Data—Continued

STATIONS OCCUPIED IN 1939—Continued

Station 2923; Apr. 26; latitude 44°10′ N., longitude 49°08′ W.; depth 88 meters; dynamic height 971.047 meters

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	−0.42	33.10	0	−0.42	33.10	26.61
26	−0.98	33.10	25	−0.95	33.10	26.63
52	−1.40	33.11	50	−1.40	33.11	26.65
78	−1.35	33.20	75	−1.35	33.19	26.72

Station 2924; Apr. 26; latitude 44°09′ N., longitude 49°02′ W.; depth 329 meters; dynamic height 971.049 meters

0	−0.48	33.06	0	−0.48	33.06	26.58
24	−0.58	33.08	25	−0.60	33.08	26.60
48	−1.34	33.11	50	−1.35	33.11	26.65
73	−1.34	33.14	75	−1.35	33.15	26.68
97	−1.37	33.22	100	−1.35	33.23	26.75
145	−0.80	33.43	150	−0.70	33.52	26.97
193	0.49	33.84	200	0.60	33.88	27.18
290	1.68	34.29	300	1.75	34.32	27.47

Station 2925; Apr. 26; latitude 44°07′ N., longitude 48°55′ W.; depth 1,545 meters; dynamic height 971.001 meters

0	−0.62	33.11	0	−0.62	33.11	26.62
21	−0.86	33.10	25	−0.95	33.11	26.64
42	−1.59	33.20	50	−1.60	33.21	26.74
64	−1.62	33.25	75	−1.50	33.29	26.80
85	−1.38	33.32	100	−1.15	33.37	26.86
127	−0.82	33.48	150	−0.20	33.69	27.08
169	0.51	33.88	200	1.40	34.20	27.40
254	2.32	34.48	300	2.60	34.53	27.56
284	*2.42	34.50	400	3.45	34.77	27.68
432	3.59	34.83	600	3.75	34.90	27.75
588	3.78	34.90	800	3.55	34.89	27.76
751	3.57	34.89	1,000	3.45	34.89	27.77
1,098	3.46	34.89				

Station 2926; Apr. 26; latitude 44°00′ N., longitude 48°29′ W.; depth 3,338 meters; dynamic height 970.902 meters

0	1.10	33.40	0	1.10	33.40	26.77
24	0.69	33.55	25	0.70	33.56	26.93
48	2.47	33.77	50	2.50	33.81	27.00
71	2.33	34.00	75	2.65	34.04	27.17
95	4.39	34.35	100	4.15	34.34	27.26
143	1.49	34.26	150	1.50	34.28	27.45
191	2.30	34.49	200	2.50	34.53	27.57
286	4.16	34.88	300	4.15	34.89	27.70
340	4.13	34.91	400	4.05	34.92	27.74
520	3.82	34.93	600	3.70	34.92	27.78
705	3.57	34.90	800	3.50	34.91	27.79
905	3.51	34.92	1,000	3.45	34.92	27.80
1,337	3.31	34.90				

Station 2927; Apr. 26; latitude 43°48′ N., longitude 47°37′ W.; depth 3,685 meters; dynamic height 970.944 meters

0	4.22	33.76	0	4.22	33.76	26.80
23	4.15	33.81	25	4.15	33.93	26.94
46	4.10	33.94	50	4.10	33.95	26.96
70	4.16	33.98	75	4.15	33.99	26.99
93	4.02	34.06	100	4.05	34.11	27.10
139	4.83	34.57	150	4.75	34.58	27.39
185	4.37	34.62	200	4.45	34.68	27.50
278	5.03	34.93	300	4.95	34.93	27.64
338	4.73	34.93	400	4.45	34.93	27.70
520	4.15	34.94	600	3.95	34.93	27.75
709	3.77	34.92	800	3.70	34.92	27.78
893	3.65	34.92	1,000	3.60	34.92	27.79
1,271	3.53	34.93				

Station 2928; Apr. 27; latitude 43°34′ N., longitude 46°30′ W.; depth (no sounding); dynamic height 971.110 meters

0	11.74	35.22	0	11.74	35.22	26.83
25	11.76	35.23	25	11.76	35.23	26.83
49	11.83	35.25	50	11.80	35.25	26.84
74	11.53	35.26	75	11.50	35.26	26.91
98	12.22	35.47	100	12.20	35.47	26.94
148	10.92	35.24	150	10.85	35.22	26.99
197	8.48	34.82	200	8.45	34.82	27.09
295	8.22	35.02	300	8.20	35.02	27.28
375	7.34	35.05	400	7.00	35.04	27.47
557	4.91	34.92	600	4.75	34.92	27.66
739	4.32	34.94	800	4.10	34.93	27.74
937	3.66	34.90	1,000	3.55	34.90	27.77
1,351	3.45	34.90				

Station 2929; Apr. 27; latitude 43°15′ N., longitude 45°07′ W.; depth 3,923 meters; dynamic height 971.562 meters

0	15.77	36.06	0	15.77	36.06	26.63
22	15.90	36.07	25	15.90	36.07	26.60
43	15.91	36.08	50	15.90	36.07	26.60
66	15.93	36.07	75	15.90	36.07	26.60
87	15.92	36.07	100	15.90	36.07	26.60
131	15.86	36.05	150	15.25	35.87	26.60
174	14.37	35.67	200	14.00	35.63	26.69
261	*13.40	35.54	300	12.20	35.32	26.82
306	12.11	35.30	400	12.60	35.46	26.85
451	12.76	35.61	600	11.55	35.21	26.86
593	*9.14	35.22	800	6.45	34.97	27.49
730	7.44	35.01	1,000	4.40	34.93	27.70
991	4.49	34.93				

Station 2930; Apr. 27; latitude 42°49′ N., longitude 46°12′ W.; depth 4,427 meters; dynamic height 971.596 meters

0	17.27	36.38	0	17.27	36.38	26.52
26	17.27	36.37	25	17.27	36.37	26.52
52	17.29	36.37	50	17.28	36.37	26.50
78	17.31	36.37	75	17.28	36.37	26.50
103	17.28	36.37	100	17.25	36.37	26.52
156	17.16	36.34	150	17.18	36.35	26.52
207	16.72	36.25	200	16.75	36.26	26.55
310	15.93	36.19	300	16.00	36.20	26.69
489	14.13	35.83	400	15.12	36.05	26.77
734	8.21	35.09	600	11.65	35.48	27.04
981	5.23	34.99	800	7.05	35.04	27.46
1,233	4.51	34.99	1,000	5.15	34.99	27.67
1,743	3.71	34.95				

Station 2931; Apr. 27; latitude 42°22′ N., longitude 46°55′ W.; depth 4,070 meters; dynamic height 971.236 meters

0	14.53	35.74	0	14.53	35.74	26.65
24	14.56	35.74	25	14.55	35.74	26.65
48	14.58	35.74	50	14.55	35.74	26.65
73	14.59	35.74	75	14.55	35.74	26.65
97	14.46	35.71	100	14.40	35.70	26.66
145	13.01	35.44	150	12.95	35.44	26.76
193	12.80	35.48	200	12.65	35.47	26.85
290	11.35	35.43	300	10.85	35.27	27.03
282	10.84	35.16	400	8.55	35.11	27.30
430	7.89	35.07	600	5.55	34.99	27.62
582	5.62	35.00	800	4.70	34.98	27.71
739	4.91	34.98	1,000	4.20	34.97	27.77
1,066	4.10	34.97				

Table of Oceanographic Data—Continued

STATIONS OCCUPIED IN 1939—Continued

Station 2932; Apr. 28; latitude 42°44′ N., longitude 47°45′ W.; depth 3,612 meters; dynamic height 970.989 meters

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	5.45	33.92	0	5.42	33.92	26.80
22	7.21	34.39	25	7.45	34.42	26.92
44	8.57	34.83	50	8.40	34.80	27.07
66	7.66	34.68	75	7.40	34.63	27.09
88	7.18	34.61	100	7.00	34.61	27.13
132	6.86	34.64	150	7.00	34.72	27.22
176	7.23	34.88	200	7.05	34.90	27.35
264	5.93	34.91	300	4.85	34.82	27.57
323	4.53	34.77	400	4.60	34.84	27.61
494	4.60	34.94	600	4.45	34.98	27.74
671	4.34	34.98	800	4.15	34.96	27.76
855	4.05	34.95	1,000	3.85	34.95	27.78
1,240	*3.52	34.96				

Station 2933; Apr. 28; latitude 43°06′ N., longitude 48°32′ W.; depth 2,451 meters; dynamic height 970.908 meters

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	1.45	33.46	0	1.45	33.46	26.80
25	1.34	33.58	25	1.34	33.58	26.90
51	1.91	33.81	50	1.85	33.80	27.04
76	3.10	34.12	75	3.05	34.11	27.19
102	3.76	34.32	100	3.70	34.26	27.25
153	3.62	34.52	150	3.65	34.51	27.45
204	4.09	34.70	200	4.05	34.68	27.54
306	4.25	34.87	300	4.25	34.86	27.67
392	4.04	34.92	400	4.00	34.92	27.75
591	3.71	34.92	600	3.70	34.92	27.78
792	3.55	34.91	800	3.55	34.91	27.78
999	3.45	34.92	1,000	3.45	34.92	27.80
1,424	3.28	34.90				

Station 2934; Apr. 28; latitude 43°19′ N., longitude 49°03′ W.; depth 1,371 meters; dynamic height 970.981 meters

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	−0.81	32.87	0	−0.81	32.87	26.44
24	−1.36	32.97	25	−1.40	32.97	26.54
47	−1.64	33.22	50	−1.65	33.25	26.77
71	−1.26	33.36	75	−1.20	33.38	26.87
94	−0.79	33.48	100	−.65	33.52	26.97
141	0.49	33.84	150	.65	33.92	27.22
188	1.38	34.21	200	1.55	34.27	27.44
282	2.72	34.61	300	2.85	34.64	27.63
239	*1.92	34.43	400	3.65	34.82	27.70
399	3.66	34.82	600	3.80	34.89	27.74
558	3.85	34.88	800	3.55	34.90	27.77
754	3.60	34.90	1,000	3.50	34.90	27.78
1,196	3.46	34.90				

Station 2935; Apr. 28; latitude 42°32′ N., longitude 49°07′ W.; depth 2,570 meters; dynamic height 970.916 meters

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	1.42	33.44	0	1.42	33.44	26.79
24	1.32	33.43	25	1.30	33.43	26.78
48	0.46	33.40	50	.50	33.41	26.82
72	2.30	33.86	75	2.25	33.90	27.09
96	1.17	34.09	100	1.25	34.12	27.35
144	2.60	34.47	150	2.60	34.49	27.53
192	2.73	34.56	200	2.80	34.57	27.58
288	3.43	34.75	300	3.50	34.78	27.68
322	3.67	34.82	400	3.85	34.88	27.72
491	3.95	34.92	600	3.85	34.92	27.76
665	3.78	34.92	800	3.60	34.90	27.77
847	3.53	34.90	1,000	3.40	34.90	27.79
1,229	3.34	34.89				

Station 2936; Apr. 29; latitude 42°00′ N., longitude 48°22′ W.; depth 3,420 meters; dynamic height 970.960

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	3.08	33.53	0	3.08	33.53	26.73
26	3.20	33.54	25	3.20	33.54	26.72
51	2.22	33.64	50	2.25	33.63	26.88
77	2.63	33.74	75	2.65	33.74	26.93
102	1.86	33.86	100	1.90	33.85	27.08
154	1.83	34.16	150	1.80	34.13	27.31
205	2.85	34.45	200	2.80	34.42	27.46
307	3.76	34.76	300	3.70	34.75	27.64
340	4.10	34.83	400	4.15	34.89	27.70
515	4.19	34.92	600	4.05	34.94	27.75
695	3.89	34.94	800	3.75	34.93	27.77
883	3.67	34.925	1,000	3.55	34.92	27.79
1,278	3.34	34.89				

Station 2937; Apr. 29; latitude 41°25′ N., longitude 47°35′ W.; depth 4,006 meters; dynamic height 970.939 meters

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	2.64	33.35	0	2.64	33.35	26.62
27	0.48	33.44	25	.50	33.43	26.83
53	1.14	33.80	50	1.05	33.74	27.05
80	6.02	34.62	75	5.30	34.52	27.28
106	6.04	34.66	100	6.05	34.66	27.30
159	5.15	34.68	150	5.20	34.67	27.41
212	5.04	34.78	200	5.10	34.75	27.49
318	4.67	34.88	300	4.70	34.87	27.63
426	4.47	34.95	400	4.50	34.94	27.70
639	4.12	34.96	600	4.20	34.95	27.75
855	3.79	34.93	800	3.90	34.93	27.76
1,072	3.64	34.94	1,000	3.70	34.94	27.79
1,509	3.43	34.92				

Station 2938; Apr. 29; latitude 41°08′ N., longitude 48°41′ W.; depth 2,908 meters; dynamic height 971.283 meters

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	16.27	36.06	0	16.27	36.06	26.51
27	15.79	35.93	25	15.80	35.93	26.53
54	15.72	35.92	50	15.70	35.92	26.54
81	15.85	36.03	75	15.80	36.02	26.59
108	14.74	35.78	100	14.80	35.85	26.68
163	14.81	35.91	150	14.75	35.87	26.71
216	14.91	35.98	200	14.85	35.97	26.77
324	11.80	35.48	300	12.65	35.59	26.93
433	8.63	35.13	400	9.50	35.22	27.23
648	4.80	34.88	600	5.35	34.90	27.57
864	4.59	34.99	800	4.65	34.98	27.72
1,081	4.18	34.98	1,000	3.35	34.99	27.76
1,515	3.63					

Station 2939; Apr. 29; latitude 42°09′ N., longitude 49°39′ W.; depth 3,200 meters; dynamic height 971.101 meters

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	11.27	34.85	0	11.27	34.85	26.64
24	11.31	34.88	25	11.30	34.88	26.65
48	10.59	34.83	50	10.55	34.84	26.75
72	10.88	35.05	75	10.85	35.06	26.87
96	10.67	35.08	100	10.55	35.07	26.93
144	9.55	34.94	150	9.50	34.95	27.02
192	9.20	35.06	200	9.05	35.06	27.18
288	7.86	34.99	300	7.65	34.98	27.33
349	6.98	34.96	400	6.30	34.96	27.50
530	5.11	34.96	600	4.85	34.96	27.68
716	4.47	34.96	800	4.25	34.95	27.74
904	4.04	34.94	1,000	3.95	34.94	27.76
1,289	3.75	34.95				

Table of Oceanographic Data—Continued

STATIONS OCCUPIED IN 1939—Continued

Station 2940; Apr. 30; latitude 41°33′ N., longitude 50°31′ W.; depth 4,161 meters; dynamic height 971.157 meters

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	15.72	35.98	0	15.72	35.98	26.58
22	15.72	35.98	25	15.72	35.98	26.58
44	15.72		50	15.72	35.99	26.59
66	15.74	35.99	75	15.70	35.99	26.59
88	15.72	35.995	100	15.00	35.88	26.66
132	12.30	35.28	150	11.85	35.26	26.84
176	11.39	35.24	200	10.95	35.24	26.99
264	9.90	35.22	300	9.50	35.20	27.21
278	10.13	35.25	400	7.35	35.04	27.42
421	6.71	35.00	600	3.45	34.78	27.68
569	3.46	34.76	800	3.80	34.92	27.77
772	3.81	34.92	1,000	3.65	34.92	27.78
1,249	3.52	34.90				

Station 2941; Apr. 30; latitude 41°58′ N., longitude 50°44′ W.; depth 4,070 meters; dynamic height 970.971 meters

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	−0.41	33.19	0	−0.41	33.19	26.70
25	−0.60	33.20	25	−0.60	33.20	26.70
50	−1.34	33.28	50	−1.34	33.28	26.79
74	−0.64	33.51	75	−0.60	33.52	26.96
99	1.90	33.83	100	1.90	33.85	27.08
149	1.58	34.10	150	1.60	34.11	27.31
198	3.54	34.49	200	3.55	34.49	27.44
297	3.68	34.56	300	2.70	34.57	27.59
387	3.90	34.83	400	3.90	34.84	27.69
585	3.76	34.89	600	3.75	34.89	27.74
786	3.73	34.91	800	3.70	34.91	27.77
989	3.54	34.90	1,000	3.55	34.90	27.77
1,403	3.40	34.90				

Station 2942; Apr. 30; latitude 42°25′ N., longitude 50°41′ W.; depth 3,017 meters; dynamic height 970.920 meters

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	1.83	33.35	0	1.83	33.35	26.68
23	1.84	33.35	25	1.85	33.35	26.68
46	2.03	33.47	50	2.00	33.51	26.81
69	1.37	33.67	75	1.35	33.74	27.03
91	1.60	33.97	100	1.85	34.10	27.28
137	2.82	34.46	150	3.10	34.53	27.52
183	3.69	34.67	200	3.95	34.73	27.59
274	4.64	34.95	300	4.65	34.96	27.71
340	4.65	34.96	400	4.55	34.96	27.72
525	4.28	34.96	600	4.15	34.97	27.77
721	4.07	34.98	800	3.95	34.97	27.79
920	3.80	34.96	1,000	3.70	34.95	27.80
1,337	3.54	34.93				

Station 2943; Apr. 30—May 1; latitude 42°48′ N., longitude 50°32′ W.; depth 1,143 meters; dynamic height 971.069 meters

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	−0.62	32.99	0	−0.62	32.99	26.53
25	−0.64	33.00	25	−0.64	33.00	26.55
50	−1.36	33.15	50	−1.36	33.15	26.68
75	−1.52	33.24	75	−1.52	33.24	26.76
100	−1.37	33.32	100	−1.37	33.32	26.82
150	−0.45	33.57	150	−0.45	33.57	27.00
201	0.48	33.86	200	0.45	33.86	27.18
301	1.88	34.24	300	1.85	34.21	27.37
251	*1.30	34.02	400	2.70	34.48	27.51
			(600)	3.85	34.87	27.72
			(800)	3.60	34.90	27.77
			(1,000)	3.60	34.94	27.80

Station 2944; May 1; latitude 42°54′ N., longitude 50°31′W.; depth 329 meters; dynamic height 971.070 meters.

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	−0.46	33.04	0	−0.46	33.04	26.57
22	−0.48	33.04	25	−0.50	33.04	26.57
44	−1.06	33.11	50	−1.20	33.13	26.66
66	−1.40	33.18	75	−1.40	33.19	26.72
88	−1.41	33.19	100	−1.40	33.21	26.74
132	−1.34	33.30	150	−1.25	33.35	26.84
177	−1.02	33.43	200	−0.90	33.46	26.93
265	−0.72	33.50	(300)	−0.70	34.05	27.39

Station 2945; May 1; latitude 42°58′ N., longitude 50°30′ W.; depth 153 meters; dynamic height 971.066 meters.

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	−0.45	33.08	0	−0.45	33.08	26.60
20	−0.46	33.07	25	−0.50	33.08	26.60
41	−1.00	33.12	50	−1.25	33.16	26.69
61	−1.39	33.20	75	−1.35	33.20	26.73
81	−1.34	33.20	100	−1.35	33.21	26.74
122	−1.40	33.24	(150)	−1.30	33.31	26.81

Station 2946; May 1; latitude 43°05′ N., longitude 50°28′ W.; depth 88 meters; dynamic height 971.072 meters.

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	0.22	33.06	0	0.22	33.06	26.55
27	0.23	33.08	25	0.25	33.08	26.57
53	−.46	33.12	50	−.35	33.11	26.61
80	−.85	33.16	75	−.75	33.15	26.66

Station 2947; May 1; latitude 43°24′ N., longitude 50°22′ W.; depth 59 meters; dynamic height 971.085 meters.

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	1.96	33.00	0	1.96	33.00	26.40
26	1.74	33.01	25	1.75	33.01	26.43
47	0.91	33.05	50	0.70	33.06	26.52

Station 2948; May 1; latitude 43°12′ N., longitude 50°42′ W.; depth 88 meters; dynamic height 971.081 meters.

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	1.31	33.04	0	1.31	33.04	26.48
24	0.91	33.05	25	0.90	33.05	26.50
48	−.24	33.12	50	−.30	33.13	26.63
72	−.67	33.18	75	−.70	33.19	26.70

Station 2949; May 1; latitude 43°02′ N., longitude 50°58′ W.; depth 732 meters; dynamic height 971.066 meters.

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	2.20	33.15	0	2.20	33.15	26.50
25	2.81	33.29	25	2.81	33.29	26.55
49	0.40	33.34	50	0.40	33.36	26.78
74	5.17	34.04	75	5.15	34.04	26.92
98	3.17	33.88	100	3.20	33.89	27.00
147	4.63	34.18	150	4.60	34.18	27.09
197	3.46	34.12	200	3.40	34.12	27.17
295	2.86	34.24	300	2.90	34.26	27.33
362	3.32	34.46	400	3.35	34.54	27.50
553	3.38	34.76	(600)	3.35	34.81	27.72

Table of Oceanographic Data—Continued

STATIONS OCCUPIED IN 1939—Continued

Station 2950; May 1; latitude 42°54′ N., longitude 51°05′ W.; depth 1,463 meters; dynamic height 971.092 meters.

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	1.41	33.16	0	1.41	33.16	26.56
25	7.98	34.43	25	7.98	34.43	26.84
51	8.65	34.58	50	8.65	34.58	26.86
76	6.32	34.19	75	6.35	34.19	26.89
101	6.61	34.27	100	6.55	34.27	26.93
152	------	35.01	150	9.70	34.98	27.00
203	------	35.23	200	10.25	35.23	27.10
304	6.19	34.74	300	6.30	34.75	27.34
393	4.85	34.73	400	4.85	34.73	27.50
587	4.81	34.95	600	4.80	34.95	27.68
780	3.85	34.89	800	3.80	34.89	27.74
975	3.68	34.93	1,000	3.65	34.93	27.78
1,364	3.40	34.90				

Station 2951; May 1; latitude 42°27′ N., longitude 51°30′ W.; depth 2,963 meters; dynamic height 971.097 meters.

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	7.96	34.25	0	7.96	34.25	26.71
23	7.71	34.29	25	7.70	34.28	26.77
46	4.17	33.80	50	3.75	33.79	26.86
68	3.06	33.77	75	3.35	33.79	26.90
91	4.26	33.92	100	4.70	33.99	26.93
137	6.34	34.34	150	6.70	34.43	27.03
183	7.28	34.56	200	7.15	34.59	27.09
274	6.21	34.64	300	5.60	34.61	27.32
321	5.28	34.59	400	5.15	34.71	27.45
488	5.10	34.83	600	3.90	34.81	27.67
661	3.63	34.80	800	3.85	34.91	27.75
840	3.90	34.92	1,000	3.75	34.92	27.77
1,217	3.55	34.90				

Station 2952; May 2; latitude 42°01′ N., longitude 51°55′ W.; depth 3,841 meters; dynamic height 971.020 meters

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	3.63	33.20	0	3.68	33.20	26.41
25	4.97	33.66	25	4.97	33.66	26.65
50	6.50	34.06	50	6.50	34.06	26.77
75	0.82	33.51	75	0.82	33.51	26.88
100	0.90	33.66	100	0.90	33.66	27.00
150	3.77	34.27	150	3.77	34.27	27.26
199	4.77	34.54	200	4.75	34.54	27.36
299	4.41	34.69	300	4.40	34.69	27.51
382	3.01	34.59	400	3.05	34.60	27.58
577	4.50	34.95	600	4.50	34.96	27.72
774	4.27	34.99	800	4.20	34.98	27.77
971	3.95	34.96	1,000	3.90	34.96	27.79
1,368	3.61	34.94				

Station 2953; May 2; latitude 42°01′ N., longitude 51°20′ W.; depth 3,292 meters; dynamic height 971.092 meters

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	−0.13	33.12	0	−0.13	33.12	26.62
25	−0.52	33.13	25	−.52	33.13	26.64
50	−1.21	33.22	50	−1.21	33.22	26.74
75	3.22	33.74	75	3.22	33.74	26.88
100	4.82	33.95	100	4.82	33.95	26.89
150	1.18	33.64	150	1.18	33.64	26.96
201	2.57	33.88	200	2.55	33.88	27.05
301	2.66	34.20	300	2.65	34.19	27.29
535	3.24	34.74	400	2.85	34.46	27.49
730	3.78	34.88	600	3.50	34.81	27.71
926	3.59	34.90	800	3.75	34.89	27.74
1,123	3.45	34.90	1,000	3.50	34.90	27.78
1,518	3.35	34.88				

Station 2954; May 21–22; latitude 42°00′ N., longitude 51°00′ W.; depth 3,447 meters; dynamic height 970.948 meters

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	4.05	33.10	0	4.05	33.10	26.28
25	1.63	33.21	25	1.63	33.21	26.60
50	0.27	33.54	50	.27	33.54	26.94
74	2.53	34.03	75	2.55	34.04	27.18
99	3.26	34.23	100	3.25	34.24	27.27
149	3.19	34.47	150	3.15	34.46	27.46
198	2.85	34.55	200	2.85	34.55	27.56
297	3.44	34.74	300	3.50	34.75	27.66
397	4.53	34.98	400	4.50	34.98	27.73
595	4.33	34.96	600	4.30	34.96	27.74
793	3.99	34.91	800	3.95	34.91	27.74
990	3.68	34.88	1,000	3.65	34.88	27.74
1,383	3.43	34.91				

Station 2955; May 22; latitude 42°00′ N., longitude 52°00′ W.; depth 3,823 meters; dynamic height 971.139 meters

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	7.49	33.67	0	7.49	33.67	26.33
25	12.07	34.98	25	12.07	34.98	26.58
50	10.70	34.91	50	10.70	34.91	26.78
75	11.16	35.10	75	11.16	35.10	26.85
100	11.34	35.18	100	11.34	35.18	26.87
150	7.65	34.56	150	7.65	34.56	27.00
199	5.92	34.34	200	5.90	34.34	27.06
299	5.11	34.40	300	5.10	34.41	27.22
370	6.94	34.95	400	6.75	34.98	27.45
559	5.61	35.02	600	5.25	35.00	27.67
750	4.27	34.91	800	4.15	34.91	27.72
941	3.98	34.98	1,000	3.90	34.93	27.76
1,325	3.62	34.92				

Station 2956; May 22; latitude 42°27′ N., longitude 51°34′ W.; depth 2,770 meters; dynamic height 971.086 meters

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	5.17	33.20	0	5.17	33.20	26.26
25	3.49	33.32	25	3.49	33.32	26.52
49	4.13	33.91	50	4.20	33.92	26.93
74	5.40	34.17	75	5.40	34.17	26.99
99	5.95	34.33	100	6.00	34.34	27.05
148	7.08	34.59	150	7.05	34.59	27.11
197	5.78	34.48	200	5.75	34.48	27.19
296	5.20	34.52	300	5.15	34.52	27.30
394	3.60	34.58	400	3.55	34.58	27.51
590	3.25	34.68	600	3.25	34.69	27.63
785	3.77	34.88	800	3.80	34.90	27.75
980	4.13	35.03	1,000	4.15	34.97	27.77
1,370	3.78	34.96				

Station 2957; May 22; latitude 42°54′ N., longitude 51°08′ W.; depth 1,463 meters; dynamic height 971.079 meters

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	5.47	33.23	0	5.47	33.23	26.25
25	4.08	33.18	25	4.08	33.18	26.35
51	3.80	33.76	50	3.80	33.74	26.83
76	5.19	34.09	75	5.20	34.09	26.95
101	5.17	34.12	100	5.15	34.12	26.98
152	5.77	34.30	150	5.75	34.30	27.05
203	4.90	34.30	200	4.90	34.30	27.15
304	6.05	34.75	300	6.05	34.74	27.36
392	4.15	34.67	400	4.10	34.67	27.54
591	4.15	34.90	600	4.15	34.90	27.71
793	3.75	34.90	800	3.75	34.90	27.75
990	3.58	34.90	1,000	3.55	34.90	27.77
1,385	3.44	34.90				

Table of Oceanographic Data—Continued

STATIONS OCCUPIED IN 1939—Continued

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
Station 2958; May 22, latitude 43°03′ N., longitude 51°01′ W.; depth 631 meters; dynamic height 971.069 meters.						
0	5.02	33.15	0	5.02	33.15	26.24
24	4.34	33.17	25	4.35	33.18	26.32
47	4.21	33.57	50	4.25	33.64	26.70
71	4.70	33.91	75	4.95	33.98	26.89
94	6.40	34.33	100	6.35	34.32	26.99
141	5.17	34.24	150	5.05	34.24	27.09
189	4.82	34.28	200	4.85	34.31	27.17
283	4.93	34.55	300	4.65	34.58	27.40
351	3.92	34.66	400	3.55	34.57	27.59
441	3.45	34.69	(600)	3.30	34.78	27.70
Station 2959; May 23; latitude 43°09′ N., longitude 50°43′ W.; depth 88 meters; dynamic height 971.008 meters.						
0	3.69	33.01	0	3.69	33.01	26.26
26	2.50	33.03	25	2.50	33.03	26.38
53	0.77	33.34	50	.75	33.31	26.72
79	1.07	33.56	75	1.00	33.53	26.88
Station 2960; May 23; latitude 43°22′ N., longitude 50°08′ W.; depth 62 meters; dynamic height 971.087 meters.						
0	4.24	32.92	0	4.24	32.92	26.13
26	3.55	32.95	25	3.55	32.95	26.22
53	1.76	33.00	50	2.10	33.00	26.39
Station 2961; May 23; latitude 43°01′ N., longitude 50°08′ W.; depth 88 meters; dynamic height 971.078 meters.						
0	3.42	32.92	0	3.42	32.92	26.21
26	2.51	32.96	25	2.55	32.96	26.32
52	1.37	33.10	50	1.50	33.08	26.49
78	−0.96	33.23	75	−.75	33.22	26.72
Station 2962; May 23; latitude 42°55′ N., longitude 50°08′ W.; depth 167 meters; dynamic height 971.066 meters.						
0	0.48	32.74	0	0.48	32.74	26.28
51	−1.06	33.22	25	−.45	32.88	26.44
76	−1.30	33.32	50	−1.05	33.20	26.72
102	−1.18	33.38	75	−1.30	33.32	26.82
127	−1.03	33.48	100	−1.20	33.37	26.86
153	−0.74	33.52	150	−.80	33.51	26.96
Station 2963; May 23; latitude 42°49′ N., longitude 50°08′ W.; depth 631 meters; dynamic height 971.060 meters.						
0	0.18	32.81	0	0.18	32.81	26.36
24	−.02	32.92	25	−.05	32.93	26.46
49	−.39	33.02	50	−.40	33.03	26.56
73	−1.62	33.20	75	−1.60	33.21	26.74
97	−1.54	33.32	100	−1.50	33.34	26.85
146	−0.23	33.67	150	−.35	33.70	27.09
195	0.51	33.87	200	.60	33.89	27.19
292	1.31	34.13	300	1.45	34.17	27.37
360	3.79	34.72	400	3.70	34.75	27.64
552	3.50	34.82	(600)	3.45	34.83	27.72

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
Station 2964; May 23; latitude 42°42′ N., longitude 50°08′ W.; depth 1,463 meters; dynamic height 971.028 meters.						
0	0.52	32.75	0	0.52	32.75	26.29
24	−0.25	32.88	25	−0.25	32.89	26.43
49	−0.60	32.98	50	−0.60	32.99	26.53
73	−1.43	33.15	75	−1.45	33.17	26.70
98	−1.44	33.38	100	−1.40	33.41	26.90
147	0.11	33.79	150	0.20	33.82	27.17
195	1.02	34.02	200	1.15	34.04	27.28
293	4.21	34.73	300	4.30	34.77	27.60
339	4.48	34.86	400	4.10	34.84	27.67
509	3.44	34.80	600	3.55	34.84	27.72
678	3.65	34.88	800	3.55	34.88	27.75
854	3.55	34.88	1,000	3.50	34.88	27.76
1,211	3.47	34.84				
Station 2965; May 23; latitude 42°24′ N., longitude 50°08′ W.; depth 2,917 meters; dynamic height 970.921 meters.						
0	1.72	32.60	0	1.72	32.60	26.10
25	−0.08	32.95	25	−0.08	32.95	26.48
50	0.08	33.58	50	0.08	33.58	26.97
75	0.82	33.96	75	0.82	33.96	27.24
100	2.07	34.21	100	2.07	34.21	27.36
150	2.05	34.36	150	2.05	34.36	27.48
201	2.82	34.59	200	2.80	34.59	27.59
301	3.48	34.78	300	3.45	34.78	27.68
380	4.14	34.91	400	4.10	34.92	27.74
577	3.89	34.93	600	3.85	34.93	27.76
778	3.58	34.91	800	3.55	34.91	27.78
973	3.45	34.91	1,000	3.45	34.91	27.79
1,363	3.41	34.905				
Station 2966; May 23; latitude 42°04′ N., longitude 50°08′ W.; depth 3,429 meters; dynamic height 970.968 meters						
0	2.51	32.74	0	2.51	32.74	26.15
25	1.70	32.98	25	1.70	32.98	26.40
50	−1.18	33.32	50	−1.18	33.32	26.82
75	2.32	33.82	75	2.32	33.82	27.03
100	3.22	34.06	100	3.22	34.06	27.14
150	1.12	34.12	150	1.12	34.12	27.36
200	2.01	34.36	200	2.01	34.36	27.48
300	4.61	34.84	300	4.61	34.84	27.61
388	3.67	34.79	400	3.65	34.80	27.68
580	4.04	34.94	600	4.05	34.95	27.76
770	3.97	34.97	800	3.95	34.97	27.79
963	3.84	34.96	1,000	3.80	34.96	27.80
1,349	3.56	34.94				
Station 2967; May 24; latitude 41°27′ N., longitude 50°05′ W.; depth 3,685 meters; dynamic height 971.041 meters						
0	3.07	32.80	0	3.07	32.80	26.16
25	1.18	32.92	25	1.18	32.92	26.39
50	−1.34	33.23	50	−1.34	33.23	26.75
74	−0.80	33.46	75	−0.80	33.46	26.92
99	−0.16	33.62	100	−0.15	33.62	27.03
149	0.43	33.80	150	0.45	33.81	27.14
198	3.62	34.30	200	3.65	34.31	27.30
297	4.40	34.55	300	4.50	34.58	27.42
337	6.37	35.00	400	5.75	35.00	27.60
503	4.94	34.995	600	4.45	34.98	27.74
667	4.22	34.965	800	4.00	34.95	27.77
843	3.93	34.95	1,000	3.80	34.95	27.79
1,207	3.67	34.94				

Table of Oceanographic Data—Continued

STATIONS OCCUPIED IN 1939—Continued

Station 2968; May 24; latitude 41°00′ N., longitude 50°03′ W.; depth 3,603 meters; dynamic height 971.108 meters

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	5.08	33.14	0	5.08	33.14	26.22
25	7.24	33.65	25	7.24	33.65	26.35
50	2.63	33.53	50	2.63	33.53	26.76
74	4.20	33.96	75	4.20	33.97	26.97
99	6.97	34.44	100	6.95	34.44	27.00
149	4.60	34.10	150	4.60	34.10	27.03
198	6.24	34.50	200	6.25	34.51	27.16
297	5.82	34.59	300	5.70	34.59	27.28
354	*2.39	34.25	400	3.15	34.44	27.44
533	5.47	35.01	600	5.05	34.99	27.68
718	4.28	34.94	800	4.20	34.96	27.76
906	4.20	34.98	1,000	4.10	34.98	27.78
1,294	3.66	34.95				

Station 2969; May 24; latitude 41°51′ N., longitude 49°23′ W.; depth 2,743 meters; dynamic height 970.984 meters

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	4.84	33.50	0	4.84	33.50	26.53
17	4.42	33.44	25	3.05	33.43	26.65
33	1.87	33.43	50	5.63	34.16	26.96
50	5.63	34.16	75	5.05	34.14	27.01
67	5.02	34.10	100	5.20	34.29	27.11
100	5.20	34.29	150	5.25	34.45	27.23
133	5.49	34.41	200	4.05	34.52	27.42
200	4.05	34.52	300	2.70	34.48	27.51
241	1.87	34.27	400	3.90	34.79	27.65
364	3.60	34.72	600	3.90	34.92	27.76
488	4.20	34.88	800	3.80	34.93	27.77
667	3.79	34.92	1,000	3.80	34.95	27.79
1,093	3.82	34.955				

Station 2970; May 25; latitude 41°09′ N., longitude 48°31′ W.; depth 2,981 meters; dynamic height 971.035 meters

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	14.17	34.76	0	14.17	34.76	25.99
26	12.60	34.74	25	12.60	34.74	26.29
51	4.08	33.62	50	4.20	33.63	26.70
76	1.17	33.57	75	1.15	33.57	26.91
102	2.86	33.78	100	2.75	33.77	26.95
152	1.29	33.81	150	1.30	33.80	27.08
305	3.31	34.56	200	2.00	34.04	27.22
347	3.61	34.75	300	3.30	34.54	27.51
527	4.07	34.91	400	3.85	34.83	27.68
712	4.05	34.955	600	4.10	34.93	27.74
915	3.85	34.94	800	4.00	34.95	27.77
1,352	3.42	34.91	1,000	3.75	34.94	27.78

Station 2971; May 25; latitude 41°43′ N., longitude 47°46′ W.; depth 3,813 meters; dynamic height 971.138 meters

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	15.22	35.50	0	15.22	35.50	26.32
25	15.14	35.52	25	15.14	35.52	26.35
50	11.92	35.00	50	11.92	35.00	26.63
75	11.23	35.00	75	11.23	35.00	26.76
100	11.89	35.25	100	11.89	35.25	26.82
150	11.48	35.24	150	11.48	35.24	26.90
199	11.73	35.47	200	11.70	35.47	27.03
299	8.90	35.13	300	8.85	35.13	27.26
425	6.16	34.98	400	6.55	34.99	27.49
645	4.82	35.00	600	5.00	35.00	27.70
870	4.18	34.98	800	4.35	34.99	27.76
1,087	3.66	34.94	1,000	3.85	34.95	27.78
1,522	3.34	34.915				

Station 2972; May 25; latitude 42°16′ N., longitude 48°26′ W.; depth 3,246 meters; dynamic height 970.956 meters

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	6.51	33.17	0	6.51	33.17	26.07
24	4.14	33.68	25	4.10	33.68	26.75
49	1.89	33.68	50	1.90	33.68	26.95
73	2.90	34.01	75	2.95	34.02	27.13
97	5.39	34.48	100	5.45	34.50	27.25
146	5.79	34.67	150	5.80	34.69	27.35
194	6.28	34.91	200	6.20	34.91	27.48
291	4.79	34.86	300	4.65	34.85	27.62
349	3.98	34.81	400	4.00	34.84	27.68
530	4.37	34.96	600	4.20	34.96	27.76
717	3.95	34.96	800	3.85	34.95	27.78
903	3.72	34.94	1,000	3.70	34.94	27.79
1,283	3.52	34.94				

Station 2973; May 26; latitude 42°45′ N., longitude 49°12′ W.; depth 2,140 meters; dynamic height 970.924 meters

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	2.62	32.70	0	2.62	32.70	26.10
25	1.00	33.30	25	1.00	33.30	26.70
50	2.15	33.84	50	2.15	33.84	27.05
75	2.85	34.04	75	2.85	34.04	27.15
100	3.10	34.20	100	3.10	34.20	27.26
150	3.65	34.47	150	3.65	34.47	27.42
200	3.77	34.62	200	3.77	34.62	27.53
300	4.41	34.87	300	4.41	34.87	27.66
397	4.09	34.90	400	4.05	34.90	27.72
595	3.71	34.925	600	3.70	34.92	27.78
794	3.52	34.92	800	3.50	34.92	27.80
990	3.38	34.91	1,000	3.35	34.91	27.80
1,380	3.23	34.92				

Station 2974; May 26; latitude 43°22′ N., longitude 49°02′ W.; depth 1,463 meters; dynamic height 970.911 meters

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	1.78	32.81	0	1.78	32.81	26.26
25	.69	33.06	25	.69	33.06	26.52
49	2.01	33.84	50	2.00	33.85	27.07
74	1.87	33.97	75	1.85	33.98	27.18
98	1.95	34.22	100	2.00	34.24	27.38
147	4.11	34.67	150	4.10	34.68	27.54
197	3.76	34.74	200	3.70	34.74	27.63
295	3.19	34.76	300	3.20	34.76	27.70
378	3.37	34.81	400	3.40	34.83	27.73
569	3.58	34.90	600	3.55	34.90	27.77
760	3.57	34.905	800	3.55	34.90	27.77
952	3.56	34.90	1,000	3.55	34.90	27.77
1,340	3.51	34.90				

Station 2975; May 26; latitude 43°04′ N., longitude 48°26′ W.; depth 2,780 meters; dynamic height 970.941 meters

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C.	Salinity ‰	σ_t
0	5.52	33.42	0	5.52	33.42	26.39
21	4.77	33.45	25	4.50	33.46	26.53
42	3.12	33.49	50	3.00	33.55	26.75
63	2.93	33.78	75	3.10	33.92	27.04
84	3.26	34.01	100	3.30	34.12	27.18
126	3.41	34.28	150	3.70	34.43	27.38
167	3.84	34.52	200	4.05	34.66	27.53
251	4.30	34.80	300	4.20	34.85	27.67
252	3.97	34.77	400	4.10	34.91	27.73
395	4.10	34.91	600	3.85	34.94	27.77
548	3.82	34.92	800	3.90	34.97	27.80
712	3.97	34.98	1,000	3.45	34.93	27.80
1,071	3.40	34.92				

Table of Oceanographic Data—Continued

STATIONS OCCUPIED IN 1939—Continued

Station 2976; May 26; latitude 42°45′ N., longitude 47°48′ W.; depth 3,539 meters; dynamic height 970.968 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	6.34	33.12	0	6.34	33.12	26.04
29	3.16	33.34	25	3.50	33.31	26.51
58	1.66	33.57	50	1.90	33.55	26.85
88	1.45	33.72	75	1.45	33.67	26.97
116	1.62	34.01	100	1.50	33.82	27.09
174	2.52	34.36	150	2.10	34.22	27.36
232	3.99	34.69	200	3.05	34.50	27.50
348	4.69	35.00	300	4.55	34.84	27.62
479	4.78	35.00	400	4.75	34.96	27.69
719	4.15	34.98	600	4.45	35.00	27.76
957	3.74	34.94	800	4.00	34.97	27.79
1,198	3.58	34.94	1,000	3.70	34.94	27.79
1,682	3.40	34.94				

Station 2977; May 26–27; latitude 42°34′ N., longitude 46°50′ W.; depth 4,161 meters; dynamic height 971.426 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	16.67	36.14	0	16.67	36.14	26.48
25	16.76	36.14	25	16.76	36.14	26.46
50	16.78	36 15	50	16.78	36.15	26.46
75	16.93	36.26	75	16.93	36.26	26.52
100	16.62	36.24	100	16.62	36.24	26.57
150	15.50	36.01	150	15.50	36.01	26.66
199	15.82	36.18	200	15.80	36.18	26.72
299	15.70	36.16	300	15.70	36.16	26.72
377	12.97	35.58	400	12.45	35.51	26.92
563	9.00	35.16	600	8.05	35.11	27.37
748	5.53	34.96	800	5.00	34.95	27.66
941	4.29	34.94	1,000	4.20	34.94	27.74
1,335	4.00	34.985				

Station 2978; May 27; latitude 42°24′ N., longitude 45°51′ W.; depth, 4,472 meters; dynamic height 971.358 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	14.94	35.92	0	14.94	35.92	26.71
25	14.98	35.92	25	14.98	35.92	26.71
50	14.97	35.925	50	14.97	35.92	26.71
74	14.57	35.90	75	14.55	35.90	26.78
99	14.40	35.89	100	14.35	35.89	26.81
149	13.52	35.69	150	13.50	35.69	26.84
198	13.53	35.74	200	13.50	35.74	26.88
297	13.00	35.67	300	12.95	35.66	26.93
383	11.96	35.47	400	11.65	35.42	27.00
582	8.14	35.04	600	7.85	35.03	27.34
782	5.73	35.00	800	5.60	35.00	27.62
980	4.73	34.99	1,000	4.65	34.99	27.73
1,379	3.92	34.96				

Station 2979; May 28; latitude 41°53′ N., longitude 51°17′ W.; depth 3,475 meters; dynamic height 971.203 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	17.81	35.54	0	17.81	35.54	25.75
25	17.23	35.48	25	17.23	35.48	25.84
51	17.17	35.85	50	17.20	35.85	26.13
76	12.54	34.90	75	12.60	34.91	26.43
102	11.03	34.84	100	11.10	34.84	26.65
153	14.38	35.88	150	14.25	35.86	26.81
203	10.41	35.07	200	10.65	35.10	26.93
305	6.73	34.72	300	6.95	34.74	27.24
347	4.39	34.46	400	3.85	34.50	27.42
514	3.43	34.70	600	3.75	34.83	27.69
676	4.07	34.90	800	3.85	34.90	27.74
855	3.78	34.91	1,000	3.75	34.92	27.77
1,227	3.69	34.94				

Station 2980; May 28; latitude 42°02′ N., longitude 51°54′ W.; depth 3,255 meters; dynamic height 971.160 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	18.54	35.70	0	18.54	35.70	25.69
22	14.65	35.08	25	14.45	35.06	26.16
44	12.43	34.88	50	12.45	34.93	26.47
66	12.57	35.18	75	14.00	35.54	26.62
88	14.85	35.88	100	14.75	35.88	26.72
132	14.26	35.83	150	13.55	35.65	26.78
175	12.07	35.40	200	11.35	35.35	27.00
263	9.95	35.24	300	8.80	35.13	27.27
304	8.66	35.11	400	5.85	34.91	27.52
465	4.50	34.86	600	4.70	34.97	27.71
633	4.76	34.98	800	3.85	34.91	27.75
816	3.81	34.91	1,000	3.60	34.91	27.78
1,210	3.49	34.92				

Station 2981; May 28; latitude 42°39′ N., longitude 51°08′ W.; depth 1,838 meters; dynamic height 971.102 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	5.44	33.34	0	5.44	33.34	26.33
17	5.46	33.34	25	4.95	33.48	26.50
35	4.32	33.65	50	3.45	33.68	26.81
52	3.31	33.69	75	5.40	34.12	26.95
69	5.35	34.09	100	5.55	34.18	26.98
104	5.58	34.19	150	6.75	34.46	27.05
138	6.40	34.35	200	7.35	34.71	27.16
207	7.15	34.66	300	6.55	34.78	27.32
190	7.92	34.80	400	4.10	34.57	27.46
297	6.64	34.78	600	4.05	34.82	27.66
413	3.93	34.56	800	3.90	34.90	27.74
558	4.08	34.805	(1,000)	3.75	34.92	27.77
893	3.82	34.915				

Station 2982; May 29; latitude 41°36′ N., longitude 51°30′ W.; depth 4,097 meters; dynamic height 971.672 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	22.33	36.28	0	22.33	36.28	25.12
29	22.33	36.36	25	22.32	36.35	25.17
57	22.29	36.40	50	22.30	36.39	25.21
86	20.67	36.64	75	21.20	36.57	25.65
113	19.51	36.58	100	20.00	36.61	26.00
170	18.29	36.46	150	18.60	36.50	26.28
227	17.80	36.44	200	17.95	36.45	26.42
340	16.52	36.23	300	17.20	36.35	26.51
323	16.92	36.30	400	14.90	36.01	26.80
456		35.80	600	9.55	35.23	27.22
570	10.29	35.32	800	5.95	35.03	27.60
700	7.48	35.08	(1,000)	4.50	34.98	27.73
943	4.73	34.99				

Station 2983; May 29; latitude 41°16′ N., longitude 50°37′ W.; depth 4,718 meters; dynamic height 971.142 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	16.04	35.30	0	16.04	35.30	25.99
15	15.31	35.17	25	14.50	35.04	26.13
29	14.26	35.01	50	12.10	34.69	26.35
44	13.13	34.82	75	9.60	34.22	26.43
58	11.22	34.51	100	6.15	33.71	26.54
87	8.68	34.05	150	1.00	33.50	26.86
115	3.44	33.44	200	0.25	33.68	27.05
125	2.79	33.47	300	2.85	34.44	27.47
183	−0.43	33.54	400	4.00	34.62	27.51
238	2.67	34.16	(600)	3.75	34.79	27.66
296	2.82	34.43	(800)	3.60	34.86	27.74
408	4.02	34.63	(1,000)	3.60	34.90	27.77

Table of Oceanographic Data—Continued

STATIONS OCCUPIED IN 1939—Continued

Station 2984; May 30; latitude 40°45′ N., longitude 49°46′ W.; depth 3,932 meters; dynamic height 971.230 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	17.58	35.51	0	17.58	35.51	25.78
29	16.85	35.76	25	16.95	35.73	26.11
58	15.78	35.94	50	16.05	35.92	26.46
87	14.26	35.65	75	14.80	35.76	26.62
115	14.49	35.78	100	14.30	35.72	26.70
173	13.61	35.68	150	14.00	35.73	26.76
231	12.34	35.56	200	13.05	35.63	26.88
346		35.12	300	10.40	35.31	27.14
505	6.09	34.96	400	7.80	35.02	27.34
759	4.48	34.97	600	5.20	34.96	27.64
1,014	4.00	34.96	800	4.35	34.97	27.75
1,275	3.76	34.95	1,000	4.00	34.96	27.78
1,808	3.43	34.92				

Station 2985; May 30; latitude 40°41′ N., longitude 49°05′ W.; depth 3,301 meters; dynamic height 971.361 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	17.39	35.52	0	17.39	35.52	25.83
27	18.52	35.99	25	18.50	35.98	25.92
54	18.57	36.41	50	18.55	36.36	26.19
81	17.67	36.36	75	17.80	36.37	26.39
108	17.34	36.35	100	17.40	36.35	26.47
162	15.83	36.03	150	16.15	36.11	26.58
216	15.20	36.00	200	15.35	36.01	26.69
324	12.64	35.60	300	13.35	35.72	26.90
450	8.58	35.01	400	10.15	35.22	27.12
667	5.12	34.94	600	5.70	34.94	27.56
880	4.40	34.97	800	4.65	34.96	27.71
1,124	3.68	34.92	1,000	3.95	34.95	27.77
1,644	3.47	34.93				

Station 2986; May 30; latitude 40°50′ N., longitude 48°11′ W.; depth 3,383 meters; dynamic height 971.007 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	11.91	34.40	0	11.91	34.40	26.16
24	6.70	33.89	25	6.60	33.89	26.62
49	4.95	34.04	50	4.90	34.05	26.96
73	4.50	34.11	75	4.50	34.12	27.06
98	6.79	34.55	100	6.95	34.58	27.11
147	7.93	34.93	150	7.90	34.92	27.25
195	6.06	34.69	200	5.95	34.69	27.33
293	5.09	34.82	300	5.05	34.82	27.55
417	4.28	34.86	400	4.30	34.85	27.66
635	4.28	34.95	600	4.30	34.94	27.72
857	3.88	34.925	800	3.95	34.93	27.75
1,081	3.71	34.93	1,000	3.75	34.92	27.77
1,540	3.43	34.91				

Station 2987; May 30–31; latitude 40°59′ N., longitude 47°19′ W.; depth 3,484 meters; dynamic height 971.018 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	8.94	33.40	0	8.94	33.40	25.90
25	6.88	34.11	25	6.87	34.11	26.76
50	5.99	34.24	50	5.98	34.24	26.97
75	6.47	34.38	75	6.44	34.38	27.02
100	6.53	34.47	100	6.52	34.47	27.09
150	7.94	34.87	150	7.94	34.87	27.20
200	5.83	34.62	200	5.81	34.62	27.30
300	5.10	34.77	300	5.10	34.77	27.51
423	4.59	34.86	400	4.65	34.84	27.61
634	4.37	34.965	600	4.40	34.95	27.72
847	4.09	34.97	800	4.15	34.97	27.77
1,061	3.69	34.935	1,000	3.75	34.95	27.79
1,490	3.35	34.90				

Station 2988; May 31; latitude 40°27′ N., longitude 47°18′ W.; depth 3429 meters; dynamic height 971.044 meters

Observed values			Scaled values			
Depth, meters	Temperature C°	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	10.08	33.78	0	10.08	33.78	26.00
21	11.27	34.16	25	11.05	34.08	26.07
43	7.34	33.69	50	6.40	33.72	26.52
64	5.15	33.86	75	6.90	34.22	26.84
86	8.23	34.55	100	7.35	34.49	26.99
129	5.92	34.35	150	5.95	34.44	27.14
171	5.99	34.51	200	5.15	34.53	27.30
257	4.55	34.56	300	4.05	34.64	27.51
231	4.04	34.54	400	4.10	34.86	27.69
346	3.72	34.76	600	4.10	34.92	27.74
460	4.39	34.91	800	3.80	34.89	27.74
590	4.13	34.92	(1,000)	3.55	34.89	27.76
867	3.71	34.88				

Station 2989; May 31; latitude 40°26′ N., longitude 48°50′ W.; depth 3,667 meters; dynamic height 971.422 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	18.86	36.22	0	18.86	36.22	26.02
27	18.74	36.23	25	18.75	36.23	26.04
53	18.18	36.36	50	18.25	36.34	26.25
80	17.76	36.42	75	17.80	36.41	26.42
106	17.68	36.42	100	17.65	36.42	26.46
160	17.39	36.40	150	17.45	36.41	26.50
213	16.93	36.31	200	17.10	36.34	26.53
319	14.36	35.85	300	14.85	35.94	26.75
439	11.39	35.46	400	12.35	35.57	26.98
670	5.36	34.93	600	6.75	35.05	27.51
908	4.04	34.905	800	4.30	34.91	27.70
1,152	3.95	34.94	1,000	4.00	34.92	27.75
1,665	3.46	34.92				

Station 2990; June 1; latitude 40°25′ N., longitude 49°44′ W.; depth 4,070 meters; dynamic height 971.273 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	16.30	35.32	0	16.30	35.32	25.94
28	13.74	34.92	25	13.80	34.93	26.19
56	16.13	35.95	50	15.75	35.84	26.46
84	14.32	35.60	75	14.85	35.71	26.57
111	13.79	35.55	100	13.90	35.56	26.66
167	13.32	35.58	150	13.45	35.57	26.76
223	12.06	35.40	200	12.70	35.46	26.83
334	9.97	35.21	300	10.60	35.27	27.08
551	5.61	34.85	400	8.55	35.09	27.28
818	4.58	34.97	600	5.35	34.87	27.55
1,080	4.05	34.97	800	4.60	34.97	27.72
1,355	3.65	34.925	1,000	4.20	34.97	27.77
1,911	3.36	34.90				

Station 2991; June 1; latitude 40°27′ N., longitude 50°35′ W.; depth 4,070 meters; dynamic height 971.782 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	21.29	36.35	0	21.29	36.35	25.46
28	21.19	36.37	25	21.20	36.37	25.50
56	20.67	36.37	50	20.85	36.37	25.60
84	18.74	36.43	75	19.10	36.41	26.09
111	18.46	36.44	100	18.55	36.44	26.25
166	18.13	36.46	150	18.20	36.46	26.36
222	17.92	36.45	200	18.00	36.46	26.41
333	17.50	36.42	300	17.65	36.43	26.47
552	13.93	35.79	400	16.75	36.29	26.58
822	7.61	35.08	600	12.80	35.64	26.95
1,087	4.68		800	8.10	35.12	27.37
1,348	4.14	34.945	1,000	5.25	34.99	27.66
1,861	4.05	34.92				

Table of Oceanographic Data—Continued

STATIONS OCCUPIED IN 1939—Continued

Station 2992; June 1; latitude 40°47′ N., longitude 51°08′ W.; depth 4,280 meters; dynamic height 971.798 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	21.53	36.38	0	21.53	36.38	25.41
25	21.46	36.37	25	21.46	36.37	25.42
50	19.81	36.36	50	19.81	36.36	25.87
75	18.81	36.40	75	18.81	36.40	26.17
101	18.53	36.44	100	18.55	36.44	26.25
151	18.13	36.45	150	18.15	36.45	26.37
201	17.93	36.44	200	17.90	36.44	26.42
302	17.59	36.42	300	17.60	36.42	26.47
463	15.87	36.10	400	16.80	36.26	26.54
688	11.25	35.41	600	13.05	35.68	26.92
907	6.39	35.02	800	8.65	35.17	27.33
1,145	4.21	34.90	1,000	5.15	34.95	27.64
1,641	3.60	34.90				

Station 2993; June 1; latitude 40°25′ N., longitude 51°30′ W.; depth 4,399 meters; dynamic height 971.890 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	21.14	36.32	0	21.14	36.32	25.48
28	21.19	36.35	25	21.15	36.35	25.49
55	20.06	36.50	50	20.20	36.47	25.85
83	19.75	36.58	75	19.80	36.57	26.03
110	19.03	36.53	100	19.30	36.55	26.14
165	18.34	36.48	150	18.45	36.49	26.31
220	18.03	36.46	200	18.10	36.47	26.39
330	17.63	36.43	300	17.70	36.44	26.47
454	17.06	36.34	400	17.35	36.39	26.52
679	12.99	35.66	600	14.75	35.95	26.78
903	7.86	35.10	800	10.20	35.29	27.16
1,143	5.03	34.98	1,000	6.30	35.03	27.55
1,640	3.86	34.94				

Station 2994; June 20; latitude 46°23′ N., longitude 48°53′ W.; depth 64 meters; dynamic height 971.061 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	5.27	32.76	0	5.27	32.76	25.89
28	5.11	32.75	25	5.15	32.75	25.89
57	0.02	32.96	50	0.60	32.92	26.42

Station 2995; June 20; latitude 46°09′ N., longitude 48°30′ W.; depth 88 meters; dynamic height 971.054 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	5.26	32.76	0	5.26	32.76	25.89
26	4.18	32.78	25	4.25	32.78	26.02
53	−1.43	33.06	50	−1.35	33.04	26.60
79	−1.46	33.06	75	−1.45	33.06	26.61

Station 2996; June 20; latitude 45°54′ N., longitude 48°08′ W.; depth 110 meters; dynamic height 971.048 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	5.34	32.79	0	5.34	32.79	25.91
25	3.33	32.81	25	3.33	32.81	26.14
50	−0.99	32.99	50	−0.99	32.99	26.54
75	−1.53	33.22	75	−1.53	33.22	26.75
100	−1.50	33.30	100	−1.50	33.30	26.81

Station 2997; June 20; latitude 45°50′ N., longitude 48°04′ W.; depth 180 meters; dynamic height 971.039 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	3.49	32.63	0	3.49	32.63	25.97
25	2.89	32.63	25	2.89	32.63	26.03
50	−0.56	33.15	50	−0.56	33.15	26.65
75	−1.12	33.27	75	−1.12	33.27	26.77
100	−1.27	33.44	100	−1.27	33.44	26.92
150	−0.73	33.66	150	−0.73	33.66	27.08

Station 2998; June 20; latitude 45°45′ N., longitude 47°58′ W.; depth, 640 meters; dynamic height 970.963 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	3.16	32.53	0	3.16	32.53	25.93
25	1.12	33.06	25	1.12	33.06	26.50
50	−1.26	33.41	50	−1.26	33.41	26.90
75	−0.65	33.65	75	−0.65	33.65	27.07
100	−0.16	33.84	100	−0.16	33.84	27.20
150	1.00	34.10	150	1.00	34.10	27.34
201	1.90	34.39	200	1.90	34.39	27.51
301	2.72	34.62	300	2.70	34.62	27.63
371	3.04	34.74	400	3.15	34.76	27.70
566	3.42	34.82	(600)	3.45	34.83	27.72

Station 2999; June 20; latitude 45°43′ N., longitude 47°55′ W.; depth 1,097 meters; dynamic height 970.942 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	4.17	32.66	0	4.17	32.66	25.93
25	2.02	32.81	25	2.02	32.81	26.25
50	0.25	33.54	50	0.25	33.54	26.94
75	0.00	33.71	75	0.00	33.71	27.09
100	0.93	33.96	100	0.93	33.96	27.23
150	1.82	34.32	150	1.82	34.32	27.47
200	2.38	34.52	200	2.38	34.52	27.58
300	3.05	34.69	300	3.05	34.70	27.66
306	3.03	34.73	400	3.30	34.79	27.71
473	3.42	34.83	600	3.50	34.87	27.76
650	3.54	34.88	800	3.50	34.90	27.78
843	3.50	34.91	(1,000)	3.45	34.91	27.79

Station 3000; June 20; latitude 45°36′ N., longitude 47°48′ W.; depth 1,399 meters; dynamic height 970.927 meters.

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	4.05	32.60	0	4.05	32.60	25.90
25	2.89	32.90	25	2.89	32.90	26.24
50	1.78	33.83	50	1.78	33.83	27.06
75	1.70	33.98	75	1.70	33.98	27.19
100	1.34	34.11	100	1.34	34.11	27.33
150	1.73	34.36	150	1.73	34.36	27.50
200	2.51	34.55	200	2.51	34.55	27.59
300	3.26	34.75	300	3.26	34.75	27.68
377	3.46	34.84	400	3.45	34.85	27.74
571	3.50	34.88	600	3.45	34.88	27.76
768	3.50	34.90	800	3.50	34.90	27.78
962	3.41	34.89	1,000	3.40	34.89	27.78
1,305	3.34	34.90				

Table of Oceanographic Data—Continued

STATIONS OCCUPIED IN 1939—Continued

Station 3001; June 21; latitude 45°17′ N., longitude 47°27′ W.; depth 2,752 meters; dynamic height 970.934 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	5.94	33.11	0	5.94	33.11	26.09
25	5.05	33.38	25	5.05	33.38	26.40
50	3.22	33.88	50	3.22	33.88	26.99
75	3.88	34.27	75	3.88	34.27	27.24
100	4.31	34.45	100	4.31	34.45	27.34
150	4.10	34.56	150	4.10	34.56	27.45
201	4.52	34.78	200	4.50	34.77	27.57
301	4.29	34.87	300	4.30	34.87	27.67
401	4.01	34.88	400	4.05	34.88	27.70
598	3.78	34.92	600	3.75	34.92	27.77
793	3.54	34.90	800	3.55	34.90	27.77
989	3.41	34.90	1,000	3.40	34.90	27.79
1,377	3.29	34.90				

Station 3002; June 21; latitude 45°17′ N., longitude 46°44′ W.; depth 3,127 meters; dynamic height 970.925 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	5.61	33.15	0	5.61	33.15	26.16
24	4.77	33.56	25	4.75	33.57	26.60
49	3.99	33.93	50	3.95	33.94	26.97
73	3.71	34.18	75	3.70	34.19	27.19
97	3.90	34.35	100	3.90	34.36	27.31
146	3.94	34.50	150	3.90	34.51	27.43
195	3.51	34.59	200	3.50	34.60	27.54
292	3.24	34.71	300	3.25	34.72	27.66
376	3.84	34.88	400	3.85	34.90	27.74
569	3.86	34.93	600	3.80	34.93	27.77
765	3.64	34.93	800	3.60	34.93	27.79
956	3.43	34.91	1,000	3.40	34.91	27.80
1,339	3.28	34.90				

Station 3003; June 21; latitude 45°05′ N., longitude 45°49′ W.; depth 3,466 meters; dynamic height 971.064 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	14.34	34.94	0	14.34	34.94	26.09
24	14.58	34.91	25	14.55	34.91	26.02
48	11.05	35.03	50	11.05	35.05	26.83
72	11.83	35.28	75	11.80	35.28	26.86
96	10.49	35.10	100	10.40	35.10	26.98
144	9.94	35.15	150	9.90	35.15	27.11
193	9.36	35.13	200	9.20	35.11	27.19
289	4.98	34.58	300	5.00	34.62	27.40
380	5.15	34.85	400	5.10	34.89	27.59
571	4.59	34.98	600	4.45	34.98	27.74
764	3.88	34.94	800	3.80	34.94	27.78
959	3.74	34.96	1,000	3.70	34.96	27.81
1,355	3.41	34.92				

Station 3004; June 21; latitude 44°46′ N., longitude 45°57′ W.; depth 3,612 meters; dynamic height 971.075 meters.

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	11.00	33.71	0	11.00	33.71	25.80
25	9.94	33.91	25	9.94	33.91	26.13
50	4.37	33.62	50	4.37	33.62	26.68
76	6.02	34.24	75	5.90	34.22	26.97
101	8.02	34.72	100	8.00	34.71	27.07
151	7.34	34.67	150	7.35	34.67	27.13
202	8.96	35.09	200	8.90	35.08	27.21
303	5.70	34.72	300	5.75	34.73	27.39
395	5.76	34.96	400	5.75	34.96	27.57
592	4.73	34.98	600	4.65	34.98	27.72
789	4.25	34.99	800	4.25	34.99	27.77
985	3.96	34.98	1,000	3.95	34.98	27.79
1,378	3.49	34.92				

Station 3005; June 21; latitude 44°24′ N., longitude 45°55′ W.; depth 3,649 meters; dynamic height 971.106 meters.

Observed values			Scaled values			
Depth, meters	Temperature C°	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	12.29	34.00	0	12.29	34.00	25.78
25	12.85	34.92	25	12.85	34.92	26.39
49	13.12	35.45	50	13.20	34.45	26.72
74	12.75	35.42	75	12.75	35.42	26.79
99	12.31	35.40	100	12.30	35.40	26.86
148	11.35	35.30	150	11.25	35.29	26.97
197	7.73	34.72	200	7.65	34.72	27.13
296	6.56	34.77	300	6.50	34.77	27.33
361	5.76	34.85	400	5.35	34.87	27.55
548	4.41	34.905	600	4.30	34.92	27.71
739	4.26	34.97	800	4.15	34.96	27.76
928	3.88	34.94	1,000	3.75	34.93	27.77
1,309	3.50	34.93				

Station 3006; June 21–22; latitude 44°37′ N., longitude 46°53′ W., depth 3,613 meters; dynamic height 971.029 meters.

Observed values			Scaled values			
Depth, meters	Temperature C°	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	10.58	33.47	0	10.58	33.47	25.68
25	9.58	34.00	25	9.58	34.00	26.27
50	6.11	33.76	50	6.11	33.76	26.59
75	2.54	33.76	75	2.54	33.76	26.96
99	7.71	34.76	100	7.70	34.76	27.15
149	5.87	34.52	150	5.85	34.52	27.22
199	7.05	34.84	200	7.00	34.84	27.31
298	5.33	34.78	300	5.30	34.79	27.49
395	5.17	34.94	400	5.15	34.95	27.64
594	4.56	35.00	600	4.55	35.00	27.75
794	4.22	35.01	800	4.20	35.00	27.79
990	3.89	34.965	1,000	3.85	34.96	27.79
1,380	3.50	34.94				

Station 3007; June 22; latitude 44°49′ N., longitude 47°51′ W.; depth 3,292 meters; dynamic height 970.966 meters.

Observed values			Scaled values			
Depth, meters	Temperature C°	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	6.82	32.88	0	6.82	32.88	25.80
25	4.90	33.32	25	4.90	33.32	26.37
51	2.53	33.76	50	2.55	33.75	26.95
76	4.22	34.18	75	4.15	34.17	27.14
101	4.68	34.38	100	4.65	34.37	27.24
152	5.03	34.55	150	5.05	34.54	27.32
203	4.34	34.60	200	4.35	34.59	27.44
304	4.91	34.89	300	4.90	34.89	27.62
384	4.06	34.85	400	4.00	34.85	27.69
580	3.97	34.92	600	3.90	34.92	27.76
778	3.67	34.92	800	3.60	34.92	27.79
973	3.46	34.92	1,000	3.45	34.92	27.80
1,363	3.28	34.91				

Station 3008; June 22; latitude 44°57′ N., longitude 48°27′ W., depth 1,820 meters; dynamic height 970.909 meters.

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	6.24	33.08	0	6.24	33.08	26.03
25	3.54	33.27	25	3.54	33.27	26.47
49	2.49	33.84	50	2.50	33.88	27.05
74	4.53	34.30	75	4.60	34.32	27.20
99	5.05	34.59	100	5.05	34.60	27.37
148	4.55	34.65	150	4.45	34.65	27.48
197	3.40	34.65	200	3.35	34.65	27.59
296	3.34	34.78	300	3.35	34.79	27.70
382	3.88	34.88	400	3.85	34.89	27.73
575	3.70	34.92	600	3.60	34.92	27.79
769	3.47	34.92	800	3.45	34.92	27.80
964	3.41	34.90	1,000	3.40	34.92	27.81
1,356	3.29	34.92				

Table of Oceanographic Data—Continued

STATIONS OCCUPIED IN 1939—Continued

Station 3009; June 22; latitude 44°56.5′ N., longitude 48°41′ W.; depth 1,454 meters; dynamic height 970.919 meters.

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	4.19	32.66	0	4.19	32.66	25.93
25	1.47	33.32	25	1.47	33.32	26.69
50	−0.07	33.60	50	−0.07	33.60	27.00
76	0.40	33.78	75	0.40	33.78	27.12
101	0.73	34.03	100	0.70	34.02	27.30
151	1.98	34.38	150	1.95	34.38	27.50
202	2.31	34.51	200	2.25	34.50	27.57
303	3.20	34.72	300	3.15	34.72	27.67
381	3.49	34.83	400	3.50	34.85	27.74
572	3.71	34.92	600	3.65	34.92	27.78
765	3.60	34.91	800	3.55	34.91	27.78
959	3.41	34.89	1,000	3.40	34.89	27.78
1,351	3.29	34.915				

Station 3010; June 22; latitude 44°55′.5 N., longitude 48°58′ W.; depth 622 meters; dynamic height 971.045 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	4.83	32.77	0	4.83	32.77	25.95
25	−0.56	32.91	25	−0.56	32.91	26.46
50	−1.56	33.18	50	−1.56	33.18	26.71
75	−1.46	33.34	75	−1.46	33.34	26.84
99	−1.29	33.40	100	−1.30	33.40	26.89
149	−0.68	33.62	150	−0.65	33.63	27.05
199	0.88	34.08	200	0.95	34.09	27.33
298	2.06	34.43	300	2.10	34.44	27.53
390	2.73	34.59	400	2.80	34.60	27.60
593	3.28	34.76	600	3.25	34.76	27.69

Station 3011; June 22; latitude 44°55′ N., longitude 49°07′ W.; depth 155 meters; dynamic height 971.104 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	5.19	32.77	0	5.19	32.77	25.91
25	0.21	32.85	25	0.21	32.85	26.39
50	−1.61	33.27	50	−1.61	33.27	26.79
76	−1.58	33.25	75	−1.60	33.28	26.79
101	−1.56	33.29	100	−1.55	33.29	26.80
146	−1.28	33.38	150	−1.20	33.39	26.88

Station 3012; June 23; latitude 44°58′ N., longitude 49°22′ W.; depth 71 meters; dynamic height 971.107 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	5.65	32.79	0	5.65	32.79	25.87
26	1.17	32.94	25	1.25	32.94	26.40
53	−1.06	33.11	50	−0.90	33.09	26.62

Station 3013; June 22; latitude 45°02′ N., longitude 49°37′ W.; depth 59 meters; dynamic height 971.113 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	6.27	32.83	0	6.27	32.83	25.83
18	4.98	32.80	25	3.15	32.84	26.18
41	−0.60	32.99	(50)	−1.20	33.08	26.62

Station 3014; June 23; latitude 44°18′ N., longitude 49°33′ W.; depth 46 meters; dynamic height 971.064 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	6.98	32.75	0	6.98	32.75	25.67
21	6.81	32.77	25	6.10	32.82	25.84
37	1.10	32.98				

Station 3015; June 23; latitude 44°11′ N., longitude 49°06′ W.; depth 88 meters; dynamic height 971.043 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	5.20	32.76	0	5.20	32.76	25.90
25	−1.28	33.10	25	−1.28	33.10	26.64
50	−1.40	33.21	50	−1.40	33.21	26.74
75	−1.24	33.21	75	−1.24	33.28	26.78

Station 3016; June 23; latitude 44°10′ N., longitude 48°59′ W.; depth 320 meters; dynamic height 971.012 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	4.23	32.70	0	4.23	32.70	25.95
25	1.14	32.84	25	1.14	32.84	26.33
49	−1.43	33.24	50	−1.45	33.25	26.77
74	−1.36	33.38	75	−1.35	33.39	26.88
98	−1.04	33.48	100	−1.00	33.50	26.96
147	0.12	33.82	150	0.25	33.85	27.19
197	1.32	34.16	200	1.40	34.19	27.39
295	2.62	34.57	300	2.65	34.58	27.60

Station 3017; June 23; latitude 44°08′ N., longitude 48°52′ W.; depth 1,463 meters; dynamic height 970.928 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	4.31	32.64	0	4.31	32.64	25.91
25	4.16	33.15	25	4.16	33.15	26.31
49	2.42	33.76	50	2.40	33.78	26.98
74	2.47	34.14	75	2.45	34.15	27.27
98	2.57	34.28	100	2.60	34.30	27.38
147	2.80	34.50	150	2.80	34.51	27.53
197	2.92	34.64	200	2.95	34.65	27.63
295	3.22	34.75	300	3.25	34.76	27.69
366	3.32	34.81	400	3.35	34.83	27.73
546	3.50	34.87	600	3.50	34.87	27.76
725	3.54	34.88	800	3.55	34.88	27.75
906	3.50	34.88	1,000	3.45	34.88	27.76
1,269	3.38	34.895				

Station 3018; June 23: latitude 43°59′ N., longitude 48°22′ W.; depth 3,155 meters; dynamic height 970.935 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	7.71	32.88	0	7.71	32.88	25.67
25	2.29	33.23	25	2.29	33.23	26.56
50	1.59	33.78	50	1.59	33.78	27.04
75	3.25	34.20	75	3.25	34.20	27.24
100	3.90	34.44	100	3.90	34.44	27.37
150	3.94	34.60	150	3.94	34.60	27.49
199	4.25	34.75	200	4.25	34.75	27.58
299	4.31	34.86	300	4.35	34.86	27.66
388	4.61	34.96	400	4.60	34.96	27.71
582	4.12	34.95	600	4.05	34.95	27.76
777	3.86	34.93	800	3.80	34.93	27.77
972	3.63	34.94	1,000	3.60	34.94	27.80
1,364	3.40					

Table of Oceanographic Data—Continued

STATIONS OCCUPIED IN 1939—Continued

Station 3019; June 23; latitude 43°47′ N., longitude 47°40 W.; depth 3,813 meters; dynamic height 971.003 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	9.55	33.37	0	9.55	33.37	25.77
24	7.57	33.36	25	7.50	33.36	26.07
47	5.36	33.72	50	4.80	33.73	26.71
71	1.91	33.74	75	1.70	33.75	27.01
95	1.50	33.84	100	1.50	33.88	27.13
142	3.49	34.24	150	3.80	34.30	27.27
189	4.69	34.60	200	4.75	34.65	27.45
284	4.79	34.78	300	4.75	34.81	27.58
275	4.74	34.80	400	4.35	34.88	27.67
421	4.24	34.89	600	4.05	34.94	27.75
573	4.09	34.93	800	4.15	34.98	27.77
736	4.18	34.985	1,000	3.85	34.97	27.80
1,087	3.77	34.96				

Station 3020; June 25; latitude 43°21′ N., longitude 47°05′ W.; depth 3,813 meters; dynamic height 970.982 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	9.91	33.26	0	9.91	33.26	25.63
25	7.44	33.45	25	7.44	33.45	26.16
50	2.27	33.59	50	2.27	33.59	26.85
75	3.69	34.09	75	3.69	34.09	27.12
100	4.65	34.32	100	4.65	34.32	27.20
150	5.27	34.61	150	5.27	34.61	27.36
200	4.73	34.67	200	4.73	34.67	27.47
300	4.97	34.91	300	4.97	34.91	27.63
365	4.36	34.87	400	4.40	34.89	27.67
558	4.60	35.01	600	4.50	35.00	27.75
756	4.08	34.97	800	4.00	34.97	27.79
962	3.85	34.96	1,000	3.80	34.96	27.80
1,394	3.47	34.93				

Station 3021; June 25; latitude 43°19′ N., longitude 46°00′ W.; depth 3,667 meters; dynamic height 971.220 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	14.07	34.57	0	14.07	34.57	25.86
25	16.70	35.64	25	16.70	35.64	26.09
49	15.64	35.91	50	15.65	35.92	26.55
74	15.85	36.10	75	15.80	36.11	26.66
98	15.84	36.19	100	15.80	36.19	26.73
147	15.09	36.03	150	15.00	36.02	26.78
196	14.19	35.86	200	14.05	35.85	26.85
294	8.20	34.84	300	8.20	34.82	27.12
290	9.03	35.03	400	4.70	34.54	27.36
418	4.62	34.54	600	4.35	34.84	27.64
533	4.49	34.78	800	4.10	34.93	27.74
665	4.25	34.88	(1,000)	3.95	34.95	27.77
927	4.02	34.95				

Station 3022; June 25; latitude 42°55′ N., longitude 46°07′ W.; depth 4,427 meters; dynamic height 971.527 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	19.68	36.16	0	19.68	36.16	25.75
25	19.75	36.17	25	19.75	36.17	25.74
50	17.96	36.19	50	17.96	36.19	26.22
74	17.78	36.23	75	17.78	36.23	26.29
99	17.46	36.18	100	17.45	36.18	26.33
149	17.38	36.39	150	17.35	36.39	26.52
198	16.95	36.35	200	16.85	36.34	26.60
297	*14.55	35.865	300	14.55	35.87	26.76
355	*14.81	35.96	400	13.45	35.75	26.90
531	8.93	35.01	600	8.25	35.04	27.29
709	7.39	35.07	800	6.30	35.04	27.56
885	5.34	35.01	1,000	4.85	35.01	27.72
1,237	4.32	35.025				

Station 3023; June 26; latitude 42°32′ N., longitude 46°13′ W.; depth 4,445 meters; dynamic height 971.691 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	20.67	36.36	0	20.67	36.36	25.64
25	20.69	36.37	25	20.69	36.36	25.64
49	20.70	36.36	50	20.70	36.36	25.64
74	18.78	36.46	75	18.75	36.46	26.22
97	18.34	36.47	100	18.30	36.47	26.34
147	17.88	36.45	150	17.85	36.45	26.44
196	17.66	36.44	200	17.60	36.44	26.49
293	16.77	36.27	300	16.65	36.26	26.58
529	13.13	35.72	400	15.30	36.03	26.72
800	7.84	35.15	600	11.90	35.55	27.06
1,074	5.08	35.05	800	7.85	35.15	27.43
1,343	4.68	35.07	1,000	5.45	35.06	27.69
1,887	3.58	34.97				

Station 3024; June 26; latitude 42°57′ N., longitude 46°51′ W.; depth 3,777 meters; dynamic height 971.218 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	16.81	35.78	0	16.81	35.78	26.18
26	16.82	35.78	25	16.80	35.78	26.18
51	16.75	35.78	50	16.75	35.78	26.19
77	15.23	35.87	75	15.20	35.86	26.61
102	15.72	36.11	100	15.65	36.10	26.70
155	14.21	35.80	150	14.35	35.82	26.76
206	12.94	35.65	200	13.05	35.67	26.92
308	10.14	35.29	300	10.35	35.32	27.16
409	7.28	34.95	400	7.45	34.97	27.35
617	4.50	34.90	600	4.60	34.90	27.66
827	4.16	34.95	800	4.15	34.95	27.75
1,045	3.70	34.91	1,000	3.80	34.92	27.77
1,497	3.43	34.93				

Station 3025; June 26; latitude 42°58′ N., longitude 47°33′ W.; depth 3,447 meters; dynamic height 971.093 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	15.56	35.25	0	15.56	35.25	26.05
25	16.49	35.64	25	16.49	35.64	26.14
51	14.09	35.65	50	14.15	35.65	26.68
76	12.97	35.47	75	13.00	35.48	26.78
102	11.98	35.32	100	12.00	35.33	26.86
152	11.75	35.47	150	11.75	35.47	27.02
202	9.12	35.03	200	9.35	35.06	27.13
304	4.81	34.58	300	4.80	34.58	27.38
376	4.95	34.80	400	4.95	34.85	27.58
565	4.69	34.99	600	4.60	34.99	27.73
753	4.22	34.97	800	4.10	34.96	27.77
952	3.80	34.935	1,000	3.75	34.93	27.77
1,360	3.50	34.93				

Station 3026; June 26; latitude 43°11′ N., longitude 48°10′ W.; depth 3,017 meters; dynamic height 970.990 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	9.99	33.20	0	9.99	33.20	25.57
25	9.81	33.22	25	9.81	33.32	25.61
50	2.02	33.63	50	2.02	33.63	26.90
75	4.39	34.21	75	4.39	34.21	27.14
100	6.24	34.61	100	6.24	34.61	27.23
150	5.36	34.62	150	5.36	34.62	27.36
201	6.21	34.88	200	6.20	34.88	27.45
301	5.23	34.94	300	5.25	34.94	27.62
456	4.29	34.94	400	4.55	34.94	27.70
689	3.88	34.92	600	4.00	34.93	27.75
924	3.57	34.92	800	3.70	34.92	27.78
1,149	3.45	34.91	1,000	3.50	34.92	27.80
1,593	3.32	34.90				

Table of Oceanographic Data—Continued

STATIONS OCCUPIED IN 1939—Continued

Station 3027; June 26–27; latitude 43°25′ N., longitude 49°03′ W.; depth 1,527 meters; dynamic height 970.925 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	5.47	32.77	0	5.47	32.77	25.88
23	2.00	33.00	25	1.90	33.02	26.42
45	1.18	33.66	50	1.35	33.76	27.05
68	2.42	33.99	75	2.80	34.09	27.20
90	3.10	34.28	100	3.05	34.32	27.36
135	2.73	34.40	150	2.95	34.48	27.49
181	3.57	34.67	200	3.50	34.70	27.62
271	3.20	34.74	300	3.25	34.77	27.70
278	3.29	34.78	400	3.40	34.82	27.73
431	3.44	34.84	600	3.50	34.88	27.76
592	3.52	34.88	800	3.55	34.89	27.76
754	3.53	34.88	1,000	3.50	34.89	27.77
1,095	3.53	34.90				

Station 3028; June 27; latitude 42°41′ N., longitude 49°13′ W.; depth 2,259 meters; dynamic height 970.908 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	5.72	32.90	0	5.72	32.90	25.95
25	1.98	33.26	25	1.98	33.26	26.60
49	1.16	33.74	50	1.15	33.75	27.05
74	1.41	33.99	75	1.40	34.00	27.23
98	2.41	34.29	100	2.55	34.32	27.41
147	3.44	34.58	150	3.45	34.59	27.53
196	3.40	34.68	200	3.40	34.69	27.62
294	4.20	34.88	300	4.20	34.89	27.70
390	4.27	34.96	400	4.25	34.96	27.75
585	4.04	34.95	600	4.00	34.95	27.77
781	3.66	34.92	800	3.60	34.92	27.79
976	3.47	34.90	1,000	3.45	34.90	27.78
1,368	3.31	34.885				

Station 3029; June 27; latitude 42°16′ N., longitude 48°24′ W.; depth 3,283 meters; dynamic height 971.095 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	16.28	35.26	0	16.28	35.26	25.90
25	15.90	35.20	25	15.90	35.20	25.94
49	12.31	35.22	50	12.30	35.22	26.72
74	12.12	35.30	75	12.05	35.30	26.83
98	10.77	35.08	100	10.40	35.04	26.93
147	6.73	34.48	150	6.75	34.49	27.07
197	7.31	34.68	200	7.35	34.69	27.14
295	7.58	35.02	300	7.50	35.02	27.38
325	6.86	35.01	400	5.55	34.95	27.59
491	4.77	34.92	600	4.55	34.95	27.71
660	4.51	34.97	800	3.85	34.91	27.75
835	3.74	34.905	1,000	3.60	34.92	27.79
1,197	3.56	34.94				

Station 3030; June 27; latitude 41°47′ N., longitude 47°52′ W.; depth 3,722 meters; dynamic height 971.035 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	10.26	32.94	0	10.26	32.94	25.33
24	3.31	33.08	25	3.30	33.09	26.35
48	4.75	34.12	50	4.75	34.13	27.03
73	4.88	34.17	75	4.90	34.18	27.05
97	5.85	34.34	100	6.05	34.38	27.07
145	7.30	34.72	150	7.25	34.72	27.19
193	6.44	34.72	200	6.30	34.71	27.31
290	4.28	34.60	300	4.30	34.61	27.47
471	4.99	34.96	400	4.85	34.83	27.57
710	4.45	35.02	600	4.75	35.01	27.73
950	3.99	35.00	800	4.25	35.02	27.80
1,193	3.72	34.95	1,000	3.90	34.99	27.81
1,688	3.44	34.94				

Station 3031; June 27; latitude 41°22′ N., longitude 47°04′ W.; depth 4,216 meters; dynamic height 971.284 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	19.22	35.69	0	19.22	35.69	25.50
21	18.15	35.59	25	18.10	35.60	25.72
42	18.09	35.61	50	16.60	35.32	25.87
63	13.11	34.81	75	11.25	34.62	26.45
84	10.56	34.53	100	12.00	35.17	26.75
126	15.34	35.05	150	14.20	35.79	26.77
168	13.52	35.69	200	12.95	35.64	26.91
252	12.14	35.57	300	9.90	35.20	27.14
316	9.50	35.11	400	8.30	35.07	27.31
490	7.25	35.04	600	6.05	34.96	27.54
673	5.26	34.91	800	4.20	34.93	27.73
866	3.90	34.94	1,000	3.80	34.94	27.78
1,284	3.78	34.94				

Station 3032; June 28; latitude 40°40′ N., longitude 47°50′ W.; depth 3,310 meters; dynamic height 971.430 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	20.85	36.25	0	20.85	36.25	25.50
27	20.84	36.23	25	20.85	36.23	25.48
54	21.05	36.35	50	21.05	36.32	25.50
81	20.21	36.63	75	20.45	36.57	25.86
107	18.58	36.49	100	18.95	36.54	26.22
161	16.69	36.24	150	17.00	36.29	26.52
215	15.43	36.06	200	15.75	36.11	26.67
322	13.27	35.73	300	13.75	35.79	26.86
334	12.99	35.67	400	11.40	35.48	27.09
470	9.66	35.27	600	6.25	35.03	27.56
602	6.22	35.03	800	4.75	34.99	27.71
778	4.89	34.99	1,000	4.05	34.95	27.76
1,161	3.60	34.92				

Station 3033; June 28; latitude 41°07′ N., longitude 48°29′ W.; depth 3,173 meters; dynamic height 971.175 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	18.63	35.52	0	18.63	35.52	25.52
27	16.21	35.13	25	16.30	35.14	25.80
53	13.94	35.41	50	14.10	35.38	26.48
80	13.38	35.51	75	13.45	35.50	26.71
105	12.55	35.36	100	12.60	35.39	26.79
159	12.22	35.39	150	12.30	35.39	26.85
212	10.83	35.23	200	11.20	35.26	26.96
317	8.56	35.10	300	8.90	35.11	27.24
510	5.63	35.03	400	7.10	35.06	27.47
767	3.92	34.92	600	4.80	34.99	27.71
1,026	3.74	34.91	800	3.90	34.92	27.76
1,282	3.49	34.94	1,000	3.70	34.91	27.77
1,791	3.31	34.90				

Station 3034; June 28; latitude 41°26′ N., longitude 48°43′ W.; depth 3,127 meters; dynamic height 971.096 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	12.13	33.15	0	12.13	33.15	25.15
25	7.29	33.59	25	7.29	33.59	26.29
49	9.64	34.57	50	9.70	34.65	26.75
74	11.48	35.19	75	11.40	35.19	26.87
98	10.00	34.97	100	9.75	34.94	26.96
147	6.76	34.56	150	6.90	34.58	27.12
196	8.85	35.06	200	8.80	35.06	27.22
294	6.14	34.75	300	6.10	34.75	27.36
386	6.47	35.03	400	6.40	35.02	27.54
582	3.37	34.78	600	3.45	34.79	27.69
781	4.22	34.98	800	4.20	34.98	27.77
974	4.00	34.95	1,000	3.95	34.95	27.77
1,359	3.43	34.91				

Table of Oceanographic Data—Continued

STATIONS OCCUPIED IN 1939—Continued

Station 3035; June 28; latitude 41°50′ N., longitude 49°20′ W.; depth 2,743 meters; dynamic height 971.010 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	13.51	33.85	0	13.51	33.85	25.41
25	4.47	32.77	25	4.47	32.75	25.97
49	−0.12	33.33	50	−.15	33.36	26.81
74	0.08	33.59	75	.10	33.65	27.03
98	8.27	34.96	100	8.25	34.96	27.23
147	7.98	34.93	150	7.95	34.93	27.24
197	7.50	35.01	200	7.45	35.01	27.38
295	5.79	34.99	300	5.70	34.99	27.60
360	5.02	34.97	400	4.65	34.94	27.69
542	3.53	34.83	600	3.55	34.84	27.72
727	3.57	34.89	800	3.55	34.90	27.77
913	3.54	34.91	1,000	3.50	34.91	27.79
1,289	3.47	34.92				

Station 3036; June 29; latitude 41°28′ N., longitude 50°02′ W.; depth 3,676 meters; dynamic height 971.274 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	18.08	35.72	0	18.08	35.72	25.82
25	17.87	35.83	25	17.87	35.83	25.96
50	16.71	36.02	50	16.71	36.02	26.39
75	15.38	35.78	75	15.38	35.78	26.52
100	15.46	35.91	100	15.46	35.91	26.59
150	14.21	35.73	150	14.21	35.73	26.72
201	12.98	35.54	200	13.00	35.55	26.84
301	10.66	35.21	300	10.70	35.21	27.01
387	7.91	34.92	400	7.65	34.92	27.28
583	5.55	34.97	600	5.40	34.97	27.63
780	4.25	34.91	800	4.20	34.91	27.72
973	4.16	34.97	1,000	4.10	34.97	27.78
1,356	3.74	34.97				

Station 3037; June 29; latitude 41°58′ N., longitude 50°00′ W.; depth 3,429 meters; dynamic height 970.988 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	7.65	32.82	0	7.65	32.82	25.64
25	4.41	32.79	25	4.41	32.79	26.02
50	−0.36	33.15	50	−.36	33.15	26.64
74	0.04	33.48	75	.05	33.49	26.91
99	0.80	33.77	100	.80	33.79	27.10
149	1.95	34.20	150	1.95	34.21	27.37
198	2.98	34.48	200	3.00	34.49	27.50
297	4.16	34.80	300	4.15	34.82	27.65
351	4.74	34.97	400	4.65	34.98	27.72
532	4.37	34.98	600	4.25	34.98	27.76
716	4.06	34.97	800	3.95	34.95	27.77
898	3.88	34.94	1,000	3.80	34.94	27.78
1,265	3.63	34.94				

Station 3038; June 29; latitude 42°23′ N., longitude 50°08′ W.; depth 2,716 meters; dynamic height 970.939 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	7.12	32.71	0	7.12	32.71	25.63
25	2.61	33.09	25	2.61	33.09	26.41
50	1.60	33.82	50	1.60	33.82	27.08
74	1.59	33.94	75	1.60	33.94	27.17
99	2.13	34.22	100	2.20	34.23	27.36
149	2.93	34.47	150	2.95	34.47	27.49
198	3.11	34.61	200	3.15	34.62	27.59
297	4.10	34.85	300	4.10	34.85	27.68
365	3.71	34.83	400	3.70	34.84	27.71
552	3.73	34.89	600	3.75	34.89	27.74
742	*3.81	34.90	800	3.80	34.91	27.76
935	3.60	34.94	1,000	3.55	34.94	27.80
1,330	3.37	34.91				

Station 3039; June 29; latitude 42°42′ N., longitude 50°08′ W.; depth 1,454 meters; dynamic height 970.950 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	6.76	32.90	0	6.76	32.90	25.81
25	3.71	32.85	25	3.71	32.85	26.14
50	1.00	33.45	50	1.00	33.45	26.82
75	−0.87	33.60	75	−0.87	33.60	27.04
99	2.36	34.07	100	2.35	34.08	27.22
149	2.62	34.41	150	2.65	34.42	27.48
199	3.07	34.62	200	3.05	34.62	27.60
298	3.15	34.71	300	3.15	34.71	27.66
386	3.28	34.78	400	3.30	34.79	27.71
576	3.43	34.87	600	3.45	34.87	27.76
764	3.50	34.86	800	3.50	34.90	27.78
954	3.54	34.91	1,000	3.55	34.91	27.78
1,333	3.41	34.81				

Station 3040; June 29; latitude 42°48′ N., longitude 50°08′ W.; depth 677 to 576 meters; dynamic height 970.957 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	6.67	32.79	0	6.67	32.79	25.75
25	1.07	33.09	25	1.07	33.09	26.53
50	−0.51	33.51	50	−0.51	33.51	26.95
74	−0.43	33.67	75	−0.45	33.68	27.08
99	0.26	33.92	100	0.30	33.93	27.24
149	1.34	34.20	150	1.35	34.21	27.41
198	2.00	34.40	200	2.05	34.41	27.52
297	2.87	34.63	300	2.90	34.64	27.63
378	3.18	34.75	400	3.20	34.77	27.71
574	3.38	34.83	600	3.40	34.83	27.73

Station 3041; June 29; latitude 42°55.5′ N., longitude 50°08′ W.; depth 159 meters; dynamic height 971.002 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	4.83	32.65	0	4.83	32.65	25.86
26	−1.49	33.19	25	−1.50	33.18	26.71
53	−1.31	33.33	50	−1.35	33.31	26.81
79	−1.24	33.42	75	−1.25	33.41	26.90
105	−1.11	33.48	100	−1.15	33.46	26.94
153	−0.46	33.65	150	−0.55	33.64	27.05

Station 3042; June 29; latitude 43°01′ N., longitude 50°08′ W.; depth 84 meters; dynamic height 971.021 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	5.49	32.69	0	5.49	32.69	25.80
22	3.22	32.86	25	2.70	32.89	26.24
50	−0.79	33.18	50	−0.79	33.18	26.69
77	−1.18	33.34	75	−1.15	33.33	26.83

Station 3043; June 30; latitude 43°22′ N., longitude 50°08′ W.; depth 66 meters; dynamic height 971.041 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	8.90	32.81	0	8.90	32.81	25.45
25	6.42	32.86	25	6.42	32.86	25.83
50	1.21	33.02	50	1.21	33.02	26.47

Station 3044; June 30; latitude 43°06′ N., longitude 50°34′ W.; depth 88 meters; dynamic height 971.031 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	8.89	32.74	0	8.89	32.74	25.39
26	3.03	32.97	25	3.15	32.96	26.27
51	1.32	33.17	50	1.40	33.17	26.57
77	−0.94	33.20	75	−0.80	33.20	26.71

Table of Oceanographic Data—Continued

STATIONS OCCUPIED IN 1939—Continued

Station 3045; June 30; latitude 42°57′ N., longitude 50°48′ W.; depth 631 meters; dynamic height 971.043 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	8.90	32.85	0	8.90	32.85	25.47
25	4.51	33.17	25	4.51	33.17	26.30
50	5.18	33.67	50	5.18	33.67	26.63
75	0.55	33.49	75	0.55	33.49	26.88
99	4.71	34.09	100	4.75	34.11	27.02
149	5.05	34.29	150	5.05	34.30	27.14
405	2.95	34.68	200	4.70	34.40	27.25
588	3.34	34.82	300	3.70	34.56	27.49
			400	2.95	34.67	27.65
			600	3.35	34.83	27.73

Station 3046; June 30; latitude 42°47′ N., longitude 50°59′ W.; depth 1,463 meters; dynamic height 971.078 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	9.85	33.03	0	9.85	33.03	25.46
25	8.14	33.11	25	8.14	33.11	25.79
50	5.52	33.75	50	5.52	33.75	26.65
75	7.99	34.50	75	7.99	34.50	26.90
99	34	34.93	100	9.40	34.94	27.02
149		35.13	150	9.55	35.13	27.14
199	6.51	34.68	200	6.45	34.67	27.26
298	2.88	34.40	300	2.90	34.41	27.45
394	4.56	34.78	400	4.55	34.78	27.57
589	3.49	34.81	600	3.50	34.81	27.71
782	3.57	34.88	800	3.55	34.88	27.75
977	3.61	34.90	1,000	3.60	34.90	27.77
1,367	3.49	34.93				

Station 3047; June 30; latitude 42°21′ N., longitude 51°27′ W.; depth 2,780 meters; dynamic height 971.101 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	13.04	33.80	0	13.04	33.80	25.48
23	6.50	32.93	25	6.40	32.93	25.89
47	3.08	32.94	50	2.50	32.97	26.33
70	−0.80	33.21	75	−1.10	33.23	26.74
93	−1.29	33.31	100	−1.30	33.33	26.83
140	−1.18	33.45	150	−1.05	33.50	26.96
186	−0.43	33.66	200	−0.20	33.73	27.11
279	1.20	34.11	300	1.45	34.21	27.40
372	2.48	34.54	400	2.65	34.61	27.63
563	3.49	34.81	600	3.55	34.82	27.71
756	3.61	34.86	800	3.60	34.87	27.75
949	3.55	34.88	1,000	3.55	34.88	27.75
1,341	3.51	34.90				

Station 3048; June 30; latitude 42°17′ N., longitude 50°41′ W.; depth 2,579 meters; dynamic height 970.967 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	6.63	32.69	0	6.63	32.69	25.67
25	0.34	33.14	25	0.34	33.14	26.61
50	−0.13	33.32	50	−0.13	33.32	26.78
75	−0.12	33.48	75	−0.12	33.48	26.91
100	−0.06	33.68	100	−0.06	33.68	27.06
150	1.88	34.18	150	1.88	34.18	27.34
200	2.66	34.46	200	2.66	34.46	27.51
300	2.94	34.66	300	2.94	34.66	27.64
394	3.22	34.78	400	3.25	34.78	27.70
586	3.82	34.92	600	3.85	34.92	27.76
775	3.83	34.94	800	3.80	34.94	27.78
970	3.60	34.925	1,000	3.55	34.92	27.79
1,361	3.43	34.92				

Station 3049; July 10; latitude 53°43′ N., longitude 55°48′ W.; depth 111 meters; dynamic height 1937.569 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	6.21	27.45	0	6.21	27.45	21.60
25	−0.13	32.18	25	−0.13	32.18	25.85
49	−0.57	32.33	50	−0.60	32.34	26.01
74	−0.97	32.47	75	−1.00	32.48	26.13
98	−1.51	32.64	100	−1.60	32.67	26.31

Station 3050; July 10; latitude 53°50′ N., longitude 55°33′ W.; depth 195 meters; dynamic height 1937.482 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	4.21	32.09	0	4.21	32.09	25.47
25	0.06	32.42	25	0.06	32.42	26.05
50	−1.13	32.74	50	−1.13	32.74	26.35
75	−1.30	32.98	75	−1.30	32.98	26.54
101	−1.36	33.07	100	−1.35	33.07	26.62
151	−0.94	33.56	150	−0.95	33.56	27.01
181	−0.54	33.74	(200)	−0.25	33.82	27.19

Station 3051; July 10; latitude 53°56′ N., longitude 55°23′ W.; depth 168 meters; dynamic height 1937.489 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	4.55	32.00	0	4.55	32.00	25.37
25	0.34	32.35	25	0.34	32.35	25.98
49	−0.69	32.58	50	−0.70	32.60	26.23
74	−1.46	32.92	75	−1.45	32.93	26.51
98	−1.43	33.08	100	−1.40	33.10	26.64
147	−1.06	33.49	150	−1.00	33.53	26.98

Station 3052; July 10; latitude 54°10′ N., longitude 54°57′ W.; depth 168 meters; dynamic height 1937.452 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	4.91	32.20	0	4.91	32.20	25.49
25	−0.25	32.66	25	−0.25	32.66	26.25
50	−0.83	33.11	50	−0.83	33.11	26.63
75	−1.11	33.32	75	−1.11	33.32	26.81
101	−1.01	33.41	100	−1.05	33.40	26.88
151	−0.22	33.85	150	−0.25	33.84	27.20

Station 3053; July 10; latitude 54°24′ N., longitude 54°32′ W.; depth 188 meters; dynamic height 1937.478 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	3.92	31.77	0	3.92	31.77	25.25
25	−0.74	32.52	25	−0.74	32.52	26.16
51	−1.34	32.85	50	−1.35	32.84	26.43
76	−1.43	33.13	75	−1.45	33.12	26.66
102	−1.23	33.28	100	−1.30	33.27	26.78
153	−0.69	33.59	150	−0.75	33.56	27.00
178	0.20	33.96				

Station 3054; July 10; latitude 54°32′ N., longitude 54°13′ W.; depth 227 meters; dynamic height 1937.454 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	3.69	31.56	0	3.69	31.56	25.11
25	0.34	32.62	25	0.34	32.62	26.19
51	−1.25	33.13	50	−1.25	33.11	26.65
76	−0.92	33.34	75	−0.90	33.34	26.83
101	−0.78	33.50	100	−0.80	33.49	26.94
152	−0.34	33.77	150	−0.40	33.75	27.14
203	1.00	34.16	200	0.90	34.13	27.37

Table of Oceanographic Data—Continued

STATIONS OCCUPIED IN 1939—Continued

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
Station 3055; July 10; latitude 54°45′ N., longitude 53°49′ W.; depth 326 meters; dynamic height 1937.457 meters						
0	3.17	30.53	0	3.17	30.53	24.24
25	−1.39	32.42	25	−1.39	32.42	26.10
50	−1.35	32.92	50	−1.35	32.92	26.50
75	−1.00	33.32	75	−1.00	33.32	26.81
100	−0.50	33.57	100	−0.50	33.57	27.00
150	0.50	34.00	150	0.50	34.00	27.29
199	1.49	34.24	200	1.50	34.24	27.42
299	3.49	34.68	300	3.50	34.68	27.60
Station 3056; July 11; latitude 54°51′ N., longitude 53°37′ W.; depth 638 meters; dynamic height 1937.376 meters						
0	3.12	30.98	0	3.12	30.98	24.69
24	−0.47	33.47	25	−0.45	33.48	26.92
48	−0.49	33.69	50	−0.45	33.71	27.11
71	0.96	33.95	75	0.95	33.97	27.24
95	0.64	34.03	100	0.70	34.05	27.32
143	2.31	34.34	150	2.55	34.39	27.46
191	3.68	34.66	200	3.65	34.69	27.59
286	4.22	34.82	300	4.25	34.83	27.64
371	4.39	34.84	400	4.40	34.85	27.64
558	4.34	34.93	(600)	4.30	34.94	27.72
Station 3057; July 11; latitude 54°55′ N., longitude 53°28′ W.; depth 1,601 meters; dynamic height 1937.335 meters						
0	3.15	32.72	0	3.15	32.72	26.08
21	1.89	32.96	25	1.75	33.10	26.49
42	1.31	33.84	50	1.35	33.92	27.18
64	1.44	34.05	75	1.75	34.12	27.31
85	1.98	34.18	100	2.20	34.28	27.40
127	2.64	34.47	150	3.50	34.65	27.58
169	4.23	34.79	200	4.20	34.83	27.65
254	4.16	34.86	300	4.25	34.89	27.69
367	4.42	34.93	400	4.40	34.94	27.71
554	4.22	34.94	600	4.15	34.94	27.74
743	3.88	34.93	800	3.75	34.93	27.77
930	3.52	34.91	1,000	3.45	34.91	27.79
1,305	3.27	34.88	(1,500)	3.20	34.88	27.79
Station 3058; July 11; latitude 55°00′ N., longitude 53°22′ W.; depth 2,088 meters; dynamic height 1937.311 meters						
0	4.13	32.80	0	4.13	32.80	26.05
23	5.07	33.51	25	5.10	33.59	26.57
47	5.78	34.23	50	5.70	34.32	27.08
70	3.82	34.54	75	3.65	34.56	27.49
93	3.37	34.63	100	3.45	34.66	27.59
140	4.46	34.90	150	4.35	34.89	27.68
186	4.07	34.88	200	4.05	34.88	27.70
279	3.98	34.92	300	4.00	34.93	27.75
328	4.10	34.94	400	4.00	34.94	27.76
501	3.77	34.92	600	3.70	34.91	27.77
680	3.67	34.92	800	3.55	34.90	27.77
857	3.47	34.90	1,000	3.30	34.90	27.80
1,310	3.22	34.91	1,500	3.20	34.91	27.82
1,787	3.18	34.92	(2,000)	3.20	34.92	27.83

Observed values			Scaled values			
Depth, meters	Temperature C°	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
Station 3059; July 11; latitude 55°10′ N., longitude 53°02′ W.; depth 3,112 meters; dynamic height 1937.254 meters						
0	6.75	34.34	0	6.75	34.34	26.95
24	4.24	34.45	25	4.25	34.46	27.35
47	3.95	34.57	50	3.95	34.59	27.48
71	4.05	34.66	75	4.05	34.68	27.54
94	3.95	34.76	100	3.90	34.77	27.64
141	3.76	34.84	150	3.75	34.85	27.71
189	3.83	34.88	200	3.85	34.88	27.72
283	3.69	34.90	300	3.65	34.90	27.76
352	3.53	34.92	400	3.50	34.92	27.80
534	3.44	34.90	600	3.40	34.91	27.80
720	3.35	34.92	800	3.30	34.91	27.81
907	3.30	34.91	1,000	3.25	34.91	27.81
1,384	3.16	34.88	1,500	3.15	34.90	27.81
1,960	3.19	34.90	2,000	3.20	34.90	27.81
2,460	2.81	34.93	2,500	2.75	34.93	27.87
2,962	1.86	34.93	(3,000)	1.75	34.93	27.95
Station 3060; July 11; latitude 55°30′ N., longitude 52°29′ W.; depth 3,286 meters; dynamic height 1937.251 meters						
0	8.03	34.60	0	8.03	34.60	26.97
24	6.16	34.63	25	6.15	34.63	27.26
48	4.34	34.72	50	4.30	34.73	27.56
73	4.16	34.76	75	4.15	34.76	27.60
97	3.85	34.79	100	3.85	34.79	27.65
145	3.52	34.78	150	3.50	34.78	27.68
193	3.51	34.85	200	3.50	34.85	27.74
290	3.42	34.86	300	3.40	34.86	27.76
377	3.23	34.88	400	3.25	34.88	27.78
571	3.24	34.90	600	3.25	34.90	27.80
770	3.27	34.90	800	3.25	34.90	27.80
969	3.19	34.90	1,000	3.20	34.90	27.81
1,480	3.18	34.92	1,500	3.20	34.92	27.825
1,994	3.24	34.93	2,000	3.25	34.93	27.825
2,507	2.90	34.96	2,500	2.90	34.96	27.88
3,023	2.08	34.92	3,000	2.10	34.92	27.92
3,277	1.74	34.93				
Station 3061; July 11–12; latitude 56°00′ N., longitude 51°35′ W.; depth 3,619 meters; dynamic height 1937.281 meters						
0	7.90	34.67	0	7.90	34.67	27.05
23	7.87	34.66	25	7.85	34.66	27.05
45	4.71	34.73	50	4.60	34.74	27.53
68	4.31	34.77	75	4.20	34.77	27.61
90	3.95	34.76	100	3.80	34.77	27.65
135	3.38	34.82	150	3.35	34.83	27.73
180	3.36	34.84	200	3.35	34.85	27.75
270	3.30	34.86	300	3.25	34.85	27.76
325	3.20	34.85	400	3.20	34.85	27.77
501	3.22	34.86	600	3.25	34.86	27.77
689	3.25	34.87	800	3.25	34.87	27.78
876	3.25	34.88	1,000	3.20	34.88	27.79
1,366	3.19	34.89	1,500	3.20	34.89	27.80
1,831	3.21	34.87	2,000	3.20	34.91	27.82
2,325	3.20	34.95	2,500	3.15	34.95	27.85
2,834	2.84	34.96	3,000	2.65	34.95	27.90
3,356	2.13	34.90	3,500	1.95	34.90	27.92

Table of Oceanographic Data—Continued

STATIONS OCCUPIED IN 1939—Continued

Station 3062; July 12; latitude 56°40′ N., longitude 50°23′ W.; depth 3,619 meters; dynamic height 1937.254 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	7.65	34.66	0	7.65	34.66	27.08
24	6.16	34.73	25	6.15	34.73	27.34
48	4.42	34.75	50	4.40	34.75	27.56
72	4.23	34.76	75	4.20	34.76	27.60
96	3.79	34.79	100	3.75	34.79	27.66
144	3.41	34.83	150	3.40	34.83	27.73
191	3.45	34.84	200	3.45	34.84	27.73
287	3.24	34.85	300	3.25	34.85	27.76
376	3.21	34.86	400	3.20	34.86	27.78
573	3.23	34.89	600	3.20	34.89	27.80
770	3.19	34.89	800	3.20	34.89	27.80
976	3.19	34.88	1,000	3.20	34.89	27.80
1,485	3.17	34.90	1,500	3.15	34.90	27.81
2,013	3.26	34.91	2,000	3.25	34.91	27.81
2,496	3.13	34.94	2,500	3.15	34.94	27.84
2,983	2.72	34.91	3,000	2.70	34.91	27.86
3,478	1.92	34.91	3,500	1.90	34.91	27.93

Station 3063; July 12; latitude 57°13′ N., longitude 49°20′ W.; depth 3,590 meters; dynamic height 1937.244 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	7.01	34.75	0	7.01	34.75	27.24
23	4.84	34.77	25	4.80	34.77	27.54
47	4.45	34.77	50	4.45	34.77	27.58
70	4.35	34.80	75	4.30	34.81	27.63
93	4.08	34.81	100	4.05	34.82	27.66
140	3.90	34.92	150	3.90	34.92	27.76
186	3.88	34.92	200	3.85	34.92	27.76
279	3.52	34.91	300	3.50	34.90	27.78
360	3.47	34.90	400	3.40	34.89	27.78
547	3.34	34.87	600	3.30	34.87	27.78
741	3.23	34.90	800	3.20	34.89	27.80
936	3.21	34.89	1,000	3.20	34.89	27.80
1,439	3.19	34.90	1,500	3.20	34.90	27.81
2,016	3.28	34.93	2,000	3.25	34.93	27.82
2,515	3.12	34.93	2,500	3.15	34.93	27.83
3,016	2.73	34.94	3,000	2.75	34.94	27.88
3,524	1.81	34.89	3,500	1.90	34.90	27.92

Station 3064; July 12–13; latitude 57°45′ N., longitude 48°06′ W.; depth 3,426 meters; dynamic height 1937.245 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	6.98	34.71	0	6.98	34.71	27.21
24	5.28	34.75	25	5.25	34.75	27.47
48	4.46	34.79	50	4.40	34.79	27.59
72	4.13	34.80	75	4.10	34.80	27.64
96	3.82	34.85	100	3.80	34.86	27.72
144	3.64	34.88	150	3.60	34.88	27.75
193	3.56	34.88	200	3.55	34.88	27.75
289	3.48	34.89	300	3.45	34.89	27.77
376	3 ?4	34.88	400	3.30	34.88	27.78
569	3.28	34.89	600	3.25	34.89	27.79
768	3.22	34.89	800	3.20	34.89	27.80
965	3.19	34.89	1,000	3.20	34.89	27.80
1,470	3.18	34.90	1,500	3.20	34.90	27.81
1,947	3.26	34.91	2,000	3.25	34.91	27.81
2,442	2.99	34.92	2,500	2.95	34.92	27.85
2,946	2.49	34.92	3,000	2.40	34.92	27.90
3,301	1.67	34.91				

Station 3065; July 13; latitude 58°23′ N., longitude 47°03′ W.; depth 2,872 meters; dynamic height 1937.236 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	6.74	34.76	0	6.74	34.76	27.29
25	6.34	34.78	25	6.34	34.78	27.35
49	4.68	34.79	50	4.60	34.79	27.57
74	4.38	34.79	75	4.35	34.79	27.60
98	4.23	34.80	100	4.25	34.80	27.62
147	3.59	34.86	150	3.60	34.87	27.75
196	3.79	34.93	200	3.80	34.93	27.77
294	3.38	34.83	300	3.40	34.87	27.77
406	3.40	34.89	400	3.40	34.89	27.78
613	3.35	34.89	600	3.35	34.89	27.78
825	3.38	34.93	800	3.35	34.92	27.81
1,031	3.34	34.92	1,000	3.35	34.92	27.81
1,545	3.24	34.92	1,500	3.25	34.92	27.82
2,009	3.02	34.92	2,000	3.05	34.92	27.84
2,504	2.48	34.93	2,500	2.50	34.93	27.89
2,797	1.68	34.91				

Station 3066; July 13; latitude 58°45′ N., longitude 45°51′ W.; depth 2,605 meters; dynamic height 1937.262 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	7.21	34.88	0	7.21	34.88	27.31
24	6.56	34.87	25	6.55	34.87	27.40
48	5.54	34.90	50	5.50	34.90	27.56
72	5.00	34.90	75	4.95	34.90	27.62
96	4.84	34.90	100	4.80	34.90	27.64
144	4.66	34.91	150	4.70	34.92	27.67
192	4.82	35.02	200	4.80	35.02	27.74
288	4.46	34.97	300	4.40	34.97	27.74
369	4.12	34.96	400	4.05	34.95	27.76
557	3.78	34.92	600	3.75	34.91	27.76
748	3.57	34.90	800	3.55	34.90	27.77
940	3.53	34.93	1,000	3.50	34.93	27.80
1,428	3.30	34.93	1,500	3.25	34.93	27.82
1,914	3.02	34.94	2,000	2.95	34.94	27.86
2,408	2.23	34.90	(2,500)	2.10	34.90	27.90

Station 3067; July 13; latitude 59°09′ N., longitude 45°25′ W.; depth 2,158 meters; dynamic height 1937.241 meters

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	7.86	34.93	0	7.86	34.93	27.26
24	7.15	34.93	25	7.15	34.93	27.36
48	6.83	34.92	50	6.80	34.92	27.41
71	5.67	34.98	75	5.60	34.99	27.61
95	5.32	35.01	100	5.30	35.01	27.67
143	5.11	35.00	150	5.10	35.00	27.68
190	4.89	35.02	200	4.85	35.02	27.73
285	4.56	35.01	300	4.50	35.00	27.75
389	4.35	34.98	400	4.30	34.97	27.75
581	3.95	34.93	600	3.90	34.93	27.76
776	3.63	34.94	800	3.60	34.94	27.80
966	3.48	34.93	1,000	3.40	34.93	27.81
1,446	3.27	34.93	1,500	3.10	34.93	27.84
1,736	3.03	34.95	2,000	2.75	34.92	27.87
2,033	2.69	34.92				

Table of Oceanographic Data—Continued

STATIONS OCCUPIED IN 1939—Continued

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
Station 3068; July 13–14; latitude 59°20′ N., longitude 45°12′ W.; depth 1,529 meters; dynamic height 1937.392 meters						
0	2.17	33.34	0	2.17	33.34	26.66
19	.85	33.75	25	.95	33.85	27.14
38	1.31	33.99	50	1.45	34.04	27.26
57	1.57	34.07	75	2.25	34.25	27.37
76	2.38	34.26	100	3.30	34.47	27.46
114	3.78	34.57	150	4.45	34.73	27.54
153	4.47	34.74	200	5.15	34.91	27.61
229	5.49	34.97	300	5.45	34.97	27.62
271	5.12	34.97	400	5.25	34.99	27.66
479	5.07	35.00	600	4.85	35.00	27.71
687	4.73	34.99	800	4.65	34.98	27.72
878	4.56	34.97	1,000	4.35	34.96	27.74
1,395	3.54	34.93				
Station 3069; July 14; latitude 59°25′ N., longitude 45°10′ W.; depth 1,170 meters						
0	2.02	33.24	0	2.02	33.24	26.59
23	1.05	33.51	25	1.10	33.54	26.88
45	2.07	33.94	50	2.50	34.02	27.17
68	3.72	34.28	75	3.80	34.32	27.29
91	3.84	34.38	100	3.80	34.41	27.36
136	3.34	34.49	150	3.45	34.53	27.48
181	3.90	34.60	200	4.05	34.64	27.51
272	4.78	34.78	300	5.05	34.85	27.57
362	5.61	35.04	400	5.50	35.04	27.66
548	5.06	35.02	600	5.00	35.01	27.71
743	4.80	35.00	800	4.75	35.00	27.72
941	4.57	35.00	(1,000)	4.50	35.00	27.75
Station 3070; July 15; latitude 59°19′ N., longitude 44°43′ W.; depth 1,133 meters						
0	7.59	34.93	0	7.59	34.93	27.29
24	7.53	34.96	25	7.55	34.96	27.33
48	7.43	34.96	50	7.40	34.96	27.35
72	7.07	34.97	75	7.05	34.97	27.41
96	6.90	34.97	100	6.85	34.96	27.43
144	4.89	34.83	150	4.85	34.83	27.57
193	4.59	34.88	200	5.00	34.89	27.61
289	5.36	35.02	300	5.35	35.01	27.66
419	5.00	34.93	400	5.05	35.00	27.69
623	4.90	35.01	600	4.90	35.00	27.71
827	4.60	35.00	800	4.65	35.00	27.74
1,035	4.15	34.98	1,000	4.25	34.98	27.76

Observed values			Scaled values			
Depth, meters	Temperature °C	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
Station 3071; July 15; latitude 59°22′ N., longitude 44°32′ W.; depth 368 meters; dynamic height 1937.395 meters						
0	4.35	34.42	0	4.35	34.42	27.31
26	4.55	34.52	25	4.55	34.52	27.37
51	4.62	34.52	50	4.60	34.52	27.36
77	4.68	34.54	75	4.65	34.54	27.37
102	4.87	34.53	100	4.85	34.55	27.36
155	5.21	34.61	150	5.15	34.60	27.36
206	5.60	34.72	200	5.60	34.71	27.40
308	4.27	34.71	300	4.40	34.71	27.53
Station 3072; July 15; latitude 59°32′ N., longitude 44°22′ W.; depth 186 meters; dynamic height 1937.423 meters						
0	1.26	33.32	0	1.26	33.32	26.70
23	1.59	33.39	25	1.60	33.40	26.74
47	2.05	33.53	50	2.05	33.58	26.86
70	1.81	33.80	75	1.85	33.86	27.09
93	3.36	34.09	100	3.60	34.15	27.17
140	4.36	34.54	(150)	4.45	34.60	27.44
Station 3073; July 15; latitude 59°39′ N., longitude 44°15′ W.; depth 140 meters; dynamic height 1937.517 meters						
0	0.38	31.50	0	0.38	31.50	25.29
24	0.10	32.05	25	0.10	32.06	25.76
49	−0.74	32.62	50	−0.75	32.65	26.26
73	−0.24	32.97	75	−0.25	32.98	26.51
98	−0.90	33.10	100	−0.90	33.14	26.67
122	−0.08	33.47				

REPORTS FROM RECIPIENTS OF GRANTS FROM THE PENROSE FUND

HARRY R. SEIWELL, Woods Hole Oceanographic Institution

Grants No. 269 (1938) and No. 378 (1939). Investigation of internal waves in the North Atlantic Ocean.

As a consequence of an internal wave mechanism, short period vertical oscillations of the water particles cause time variations of oceanographic properties (temperature, salinity, etc.) at fixed points throughout the ocean space. Observations on the phenom-

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ena from a ship anchored on the high seas have been taken continuously over periods ranging from twenty-five hours to two weeks, and in February 1940, the previous eleven deep anchorings of *Atlantis* were supplemented by measurements while anchored for approximately forty-eight hours in the Gulf Stream off Cape Canaveral, Florida.

Magnitudes of the vertical displacements, along fixed verticals in the sea, change from day to day, with consequent diversity in daily ranges of physical and chemical properties at fixed points. Thus for example, thirteen days of continuously repeated measurements at a position (*Atlantis* 3091) about 110 miles northwest of Bermuda, at standard depths (between 50 and 1300 meters depth) have brought out that minimum 24-hourly temperature ranges varied between 0.06° and 0.90° while 24-hourly maximum ranges were between 0.26° and 2.50°, minimum temperature ranges resulted from vertical displacements of 5 to 42 meters and maximum from displacements of 28 to 149 meters.

As a result of internal waves representative structural pictures of oceanic areas are not generally obtained from isolated individual samplings of the water masses. However, disturbances appear to be insufficient to invalidate use of customary dynamic methods for computation of the broad general features of ocean currents, although consideration of detailed variations are frequently to be taken with a "grain of salt." Accuracy of patterns, prepared to illustrate dynamic states of the sea (dynamic topographies, current velocities, etc.), may be augmented by use of controlled data, and possible errors which may arise in computations of dynamic elevations of equal pressure surfaces, horizontal current velocities and water transports have been discussed for both the Western Sargasso Sea and for the Gulf Stream. In the Sargasso Sea, where dynamic slopes of equal pressure surfaces are not great and where horizontal current velocities are relatively weak, time variations of oceanographic properties are sufficient to cause discrepancies in computed average velocities up to 3.0 to 3.5 centimeters per second, or 50 to 100 per cent of computed average surface values. In deeper water (where even lower velocities prevail) percental variations increase, obtaining up to, approximately, 200 per cent at 1000 meters depth. In the Gulf Stream a somewhat similar situation prevails, for example, short period variations in current velocities of approximately 20 per cent were inferred for a computed average surface velocity of 135 centimeters per second in the axis of the current off Montauk Point.

Theoretical investigation of internal waves in a sea of continuously varying density, using methods proposed by Fjeldstad, considers computation of possible internal waves for a given density distribution by numerical integration of the second order differential equation:

$$\frac{d^2W}{dx^2} + \lambda^2 g\varphi W = 0$$

with boundary conditions

$$W = 0, \quad x = 0, \quad \text{at the bottom,}$$
$$W = 0, \quad x = h, \quad \text{at the surface,}$$

when W represents the vertical elevation of a particle from its equilibrium position. The infinite number of solutions of the equation corresponds to an infinite number of internal waves. Four orders of waves appear to be adequate to represent vertical variations, and theoretical amplitudes and phases determined by least squares are in fair agreement with those obtained by harmonic analysis of observed displacements.

To transform the observations into patterns appropriately indicating their average state and space variability, statistical techniques identified with somewhat analogous geophysical phenomena have been used. Application of probability theory to results of harmonic analysis of observations (between surface and 1200–1300 meters) illustrates dominance of 24 and 12 lunar-hour sine-waves in vertical oscillations of the water particles, although the physical nature of the phenomena is not involved. Both amplitudes and phases of vertical displacements vary continuously with depth, being identified with the internal structure of the water column, and vertical transitions closely parallel density stratification. The two groups of coefficients (for the observational interval) are conveniently represented as point aggregates in the "harmonic dial" of Bartels, and computation of their geometric properties brings out essential basic distinctions for the two frequencies. Likewise additional significance is given the analysis by comparison of observed and theoretical values, both having essentially the same statistical properties.

Contribution No. 264, Woods Hole Oceanographic Institution.

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THE DETERMINATION OF DISSOLVED ORGANIC NITROGEN IN SEA WATER*

By

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The dissolved organic nitrogen occurring in the sea has so far received the least attention of all the nitrogen-containing fractions. As Krogh (*1*) has pointed out, it is present in relatively large amounts but is apparently unavailable for use by living organisms. The present investigation was carried out to test the practicability of a more extensive study of the distribution and significance of the dissolved organic N in the sea.

The method employed has been described by Krogh and Keys (*2*). A sample of 5 ml. of sea water is introduced into a silver combustion tube, which contains a pellet of pure KOH and through which a stream of purified oxygen-free hydrogen is passed. The extended tip of the tube dips into 1 ml. of dilute HBr solution. The water is first distilled off by gentle heating, after which the tube is heated along its entire length to about 500° C., which transforms the organic nitrogen into ammonia. Then 2 ml. of "nitrogen-free" water are introduced and the process repeated, since the salt residue tends to retain some ammonia. The ammonia driven over into the HBr solution is then determined according to Krogh's modification of Teorell's method (*3*). In a separate sample of sea water pre-formed ammonia must be determined according to Krogh, and this value subtracted from that obtained in the total nitrogen determination. A blank correction must also be applied, since it is impossible to procure water entirely free of dissolved organic N. It occasionally happens that, for some reason, the ammonia is incompletely driven off. To guard against this source of error a blank run on 2 ml. of the "nitrogen-free" water is made after the analysis of each sample.

We found that it is possible with this procedure to carry out a series of four analyses and blanks without opening the combustion tube.

The method requires practice before satisfactory results are achieved. In Table I we give the analytical data from two sets of determinations, in order to illustrate the accuracy that can be

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TABLE I

COMPARISON OF SUCCESSIVE DETERMINATIONS ON TWO DIFFERENT SAMPLES OF SEA WATER. ONE MICROGRAM OF N CORRESPONDS TO 0.56 ML. OF NAPHTHYL RED

	Titration: ml. of naphthyl red			*Dissolved organic*
Sample	*Blank*	*5 ml. sea water*	*Diff.*	*$N+NH_3$ in γ per l.*
1	2.96	2.27	0.69	246
1	2.95	2.39	0.56	200
1	2.95	2.26	0.69	246
1	2.97	2.35	0.62	222
			Mean	229
2	3.80	3.28	0.52	186
2	3.84	3.28	0.56	200
2	3.79	3.27	0.52	186
2	3.81	3.30	0.51	182
			Mean	189

expected. The first is a set of average accuracy that can be obtained without great difficulty; the accuracy of the second series is obtained only after long practice, and is even then not always achieved.

A further test of the accuracy of the method was made by analyzing 6 samples of sea water 16 times each, in sets of 4 analyses at a time. All these samples had been stored in the laboratory, at room temperature and in the light, for over one year. Aged sea water was chosen, since it could be assumed that no further changes in the content of dissolved organic N would occur during the time of the analysis (1 day to 1 week). It could therefore be expected that differences in the results were due to analytical errors only. We have then calculated the mean value of the 16 determinations of each sample and the percentage deviation of each set of 4 analyses from this mean. Table II shows that the error of a set of analyses will in

TABLE II

AVERAGE DEVIATIONS IN PER CENT, IN SIX DIFFERENT SAMPLES OF SEA WATER. EACH SERIES CONTAINS FOUR ANALYSES. AVERAGE DEVIATIONS FROM THE MEAN OF SIXTEEN DETERMINATIONS

Station	*3354*	*3515*	*3245*	*3245*	*3245*	*Misc.*
Depth	*0m*	*0m*	*0m*	*800m*	*1200m*	*>1000m*
Series 1	+3	− 5	−5	−11	+5	−8
Series 2	−3	+12	±0	+ 6	−4	+4
Series 3	−3	− 9	+2	− 4	±0	−2
Series 4	+3	+ 3	+3	+ 8	−1	+6

general be well below 10%. The accuracy of the method should be enough to decide whether or not the distribution of dissolved organic N is as uniform as Krogh assumes. Table III shows the absolute values found in these and in two other samples of aged sea water. These are of some interest, since they can be compared with Krogh's fresh samples. The average of our four surface samples is 147 γ per liter; that of the 4 deep samples 214 γ. This latter figure is close to Krogh's value of 244 γ for a whole deep water column, possibly within experimental error. The values for surface water are, however, decidedly lower. Whether this is due to a stratification of the dissolved organic N in the sea, or to disappearance of nitro-

TABLE III

Dissolved Organic N in Aged Sea Water Samples
Micrograms per Liter

Station	*Depth m*	*Age of sample*	*Organic* $N+NH_3$	NH_3	*Dissolved organic N*
3354	0	16 mo.	158	0	158
3515	0	15 mo.	111	6	105
1474	0	7½ yrs.	173	45	128
3245	0	18 mo.	266	70	196
3245	800	18 mo.	238	16	222
3245	1200	18 mo.	249	10	239
1474	3000	7½ yrs.	216	8	208
Misc.	>1000	22 mo.	185	0	185

genous substances during storage, must be decided by later observations.

The method can hardly be used on ship board. It was therefore necessary to ascertain the conditions under which samples can be satisfactorily preserved for analysis after return to the laboratory. Tests were carried out on two samples of harbor water, which were analyzed immediately after sampling and again after storage for various periods under conditions indicated in Table IV. In the case of filtered samples stored in the ice box, or kept either in the dark or the light at room temperature, it seems likely that the differences between the single sets of analyses are due to analytical errors rather than to actual changes. The same applies probably to the unfiltered sample kept in the light. If the content in particulate matter is high, however, and if such a sample is stored in the dark, a considerable, but slowly diminishing, amount of dissolved organic N accumulates. This is due to the fact that under these conditions the organisms die quickly and a large part of their body substance

TABLE IV

DISSOLVED ORGANIC N IN SAMPLES OF SEA WATER STORED UNDER DIFFERENT CONDITIONS. NOT FILTERED. IN LIGHT AT ROOM TEMPERATURE

Conditions	Storage time, days	Micrograms per liter: Organic $N+NH_3$	NH_3	Dissolved organic N
*Filtered**	0	147	23	124
Dark	7	177	16	161
In refrigerator	12	158	20	138
	22	146	17	129
	28	170	16	154
Not filtered	0	147	23	124
Light	14	168	8	160
Room temperature	23	151	10	141
	28	175	4	171
*Filtered**	0	189	80	109
Dark	6	170	37	133
Room temperature				
*Filtered**	0	189	80	109
Light	6	129	9	120
Room temperature				
*Filtered**	0	189	80	109
Dark	7	152	22	130
In refrigerator				
Diatoms added	0	189	80	109
(*318 γ/liter*)	4	507	138	369
Dark	9	486	209	277
Room temperature	14	545	265	280

* With No. 4 sintered-glass filter.

goes into solution. Later, it is transformed into ammonia by bacterial activity.

For future investigations therefore, we recommend that samples of about 250 ml. be immediately filtered through No. 4 sintered glass and stored at once on ice in glass-stoppered bottles. Analysis should be carried out as soon as possible. Under these conditions differences of the order of 50 γ per liter are significant.

We acknowledge the help of Dr. J. W. Zabor in carrying out some of the ammonia determinations.

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MARINE CHITIN-DECOMPOSING BACTERIA*

By

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Chitin is found in various members of the plant and animal kingdoms. It forms the main skeletal material of the Insecta and Crustacea in the animal kingdom, and is present also in tissues of fungi. Chitin has an elementary composition of $C_{32}H_{54}O_{21}N_6$ (*6*), On hydrolysis with concentrated acid it yields glucosamine and acetic acid in proportions which indicate that there is an acetyl group for each glucosamine residue. It is a tough leathery substance, insoluble in water, in concentrated alkalis, and in the common organic solvents. No essential differences have been found in the chitin from animal and vegetable sources (*4*, *8*).

In the course of a study of the decomposition of chitinous material in natural marine media, a number of bacteria capable of decomposing chitin were isolated from marine sand, mud, and water (*7*). Chitin-decomposing bacteria were isolated also from the intestinal contents of several common marine animals. The following methods were used in the isolation of the bacteria from their respective habitats.

Purified chitin was prepared from horseshoe crab shells according to the procedure of Benton (*2*), and ZoBell and Rittenberg (*11*). The shells were treated successively for prolonged periods with 1 percent hydrochloric acid, 2 percent potassium hydroxide, and 95 percent

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ethyl alcohol. The snowy white material which remained reacted positively to simple qualitative tests for chitin (*3*).

In preparing liquid culture media, 1 by 5 cm. strips of the purified chitin were placed in test tubes, and partly covered with sea water, or with sea water containing additional nutrients (Fig. 12). The medium best suited for the detection of chitin-decomposing bacteria

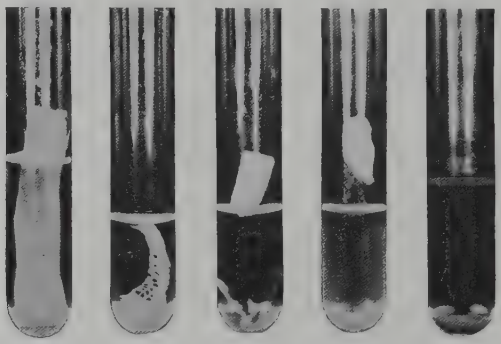

Figure 12. Decomposition of purified chitin in liquid culture medium. The tube on the left is the control; the other tubes show the chitin in various stages of breakdown.

consisted of a strip of chitin in a solution used by Waksman (*10*). This basic medium had the following composition:

glucose	1 gram
peptone	1 gram
K_2HPO_4	0.05 gram
Sea water (filtered)	1000 ml

By elimination and by substitution in this basic medium, the metabolic requirements of the bacteria were studied.

Solid media were prepared from the liquid culture media either by the addition of 15 grams of agar to each liter of solution or by diffusion of the nutrient solutions through silica gels. Where solid media were employed strips of sterile purified chitin were placed on the surface of the hardened gel (Fig. 13). The silica gel plates were prepared under as nearly aseptic conditions as possible; all other media were sterilized by autoclaving for 20 minutes at 120° C.

One additional solid medium was found useful for the rapid detection of chitin-decomposing bacteria. It was prepared by uniformly

dispersing chitin in agar according to the following procedure. Fifteen grams of purified chitin were added to 150 ml. of 1 : 1 sulfuric acid and kept overnight in the refrigerator. The chitin was dissolved by this treatment but analyses showed that it was not hydrolyzed. The following day the chitin was precipitated by the addition of approximately 140 ml. of 20 percent potassium hydroxide. The precipitate was placed on a Büchner funnel and washed repeatedly with distilled water until the filtrate was neutral to litmus. Thirty-five grams of the chitin, as removed from the filter, were then added to the basic liquid

Figure 13. Breakdown of strips of purified chitin on the surface of a silica gel plate inoculated with a sample of marine mud.

medium. After autoclaving, the agar was thoroughly shaken to redistribute the chitin, and Petri plates were poured. In this condition the medium was of a uniform milky-white opacity. When chitin-decomposing bacteria grew on the surface of this agar they dissolved the chitin, thereby producing a clear halo around each colony (Fig. 14). By noting the length of time necessary for the appearance of halos the rates of bacterial activity could be estimated. Bacteria which decomposed chitin rapidly often produced a halo after two days' growth whereas others required eight to ten days for a positive test. Although bacteria which were unable to decompose chitin often grew well on the medium, they did not alter it in appearance (Fig. 14).

The media were inoculated with sea water, marine sand or mud, a piece of decomposing horseshoe crab shell, or with a loopful of ma-

terial from the intestinal tract of a fish or other marine animal. In order to test a given sample for chitin-decomposing bacteria, several different media were inoculated. These were incubated at room temperature and examined periodically for evidence of chitin breakdown. Growth was slow in the medium consisting of only chitin in sea water, whereas the same bacteria decomposed the chitin more rapidly when additional nutrients were present.

In preliminary work cultures of bacteria which showed no evidence of chitin-decomposition were kept one year before being discarded as

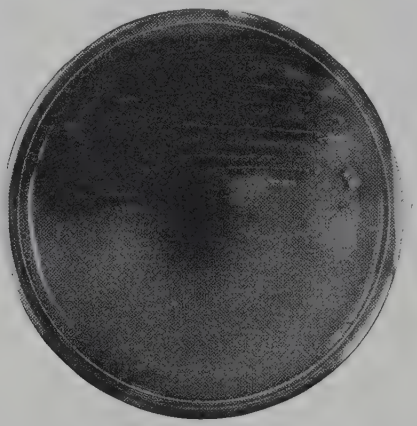

Figure 14. Growth of marine bacteria on agar containing precipitated chitin. Upper half inoculated with a pure culture of chitin decomposing bacteria: lower half inoculated with a culture incapable of attacking chitin.

negative. It became evident, however, that several weeks were adequate for detecting the chitin-decomposing capacity of most species. After bacterial development took place a second tube of enriched medium was inoculated with a loopful of material from an original positive culture. Growth from the second tube was then streaked either on nutrient agar plates or on agar medium containing precipitated chitin. In either case the colonies which developed were again retested for their ability to attack chitin. In this way pure cultures of the bacteria were obtained.

Visible dissolution of the chitin, either in liquid medium or on a solid agar surface was indisputable evidence that the chitin was being attacked. To detect incipient decomposition a hand lens was helpful.

During advanced stages of decomposition the shell was frequently observed to be "eaten" away in spots. The liberation of ammonia from media lacking peptone or nitrate, reducing substances from media lacking glucose, or a pronounced change in acidity, were further reliable evidence of chitin-decomposition.

The chitin-decomposing bacteria isolated from the sea were found to be Gram negative, asporogenous, motile rods. Among the readily demonstrable products resulting from the decomposition of purified chitin by pure cultures of the bacteria were ammonia, reducing substances, and organic acids. All of the bacteria liquefied gelatin rapidly, but failed to digest cellulose even after incubation for many weeks. Most of the bacteria were unable to hydrolyze starch: about half of them were able to reduce nitrates, but none were able to produce hydrogen sulfide. Likewise, the various cultures of bacteria differed in their ability to ferment simple sugars and alcohols. Some of the bacteria produced pigments while others did not. They also varied in the rapidity of decomposition of chitin. None of the cultures was able to grow in fresh water media. No attempt was made, however, to acclimate the bacteria by reducing the salt content of the media gradually with each successive transfer.

A description of two types of bacteria, selected as representing the marine chitin-decomposing bacteria isolated in the present investigation, is reported here. Five strains of the first type, *Bacterium chitinophilum* are described. These strains vary in their ability of reducing nitrate and of utilizing several sugars and other carbohydrates, but appear to be sufficiently similar to warrant placing them together as one type. From the description given by Benecke (*1*), his *Bacillus chitinovorous* might be identical with either Strain I, II, or III. Rammelberg (*9*) and Folpmers (*5*) each isolated a bacterium, the former from harbor water, the latter from the soil, which apparently correspond to the one described by Benecke. Benton (*2*) described 17 types of chitin-decomposing bacteria, but was unable to identify any of these with *B. chitinovorous*. Two of her groups, according to the description given, could be identical with Strain I or Strain IV of *B. chitinophilum*. Except for color, Strain IV is identical with one of 14 types described by ZoBell (*11*). *Bacterium chitinochroma*, the second type isolated in this study, is represented by a single strain.

Bacterium chitinophilum, n. sp.

Short rods, .35 to .65 by .95 to 1.5 microns in size. Gram negative. Motile.

Basic agar plate: colonies circular, smooth, entire, raised, white.

TABLE I

Name	Average Size (microns)	Color on Chitin Medium	Gram Stain	Motility	Nitrate Reduction	Starch Hydrolysis	Gelatin Liquefaction	H_2S Production	Cellulose Digestion	Dextrose	Sucrose	Lactose	Glycerol	Mannitol	Sources
Bacterium chitinophilum Strain I	0.5 × 1.2	White	−	+	+	−	+	−	−	+	+	−	+	+	Mud, intestines of horseshoe crab and dogfish.
Strain II	0.5 × 1.4	White	−	+	+	−	+	−	−	+	+	+	+	+	Water, mud, intestines of puffer.
Strain III	0.5 × 1.2	White	−	+	+	−	+	−	−	+	+	−	−	−	Water, sand, mud.
Strain IV	0.5 × 1.2	White	−	+	+	−	+	−	−	+	−	−	+	+	Intestines of quahaug and sand crab
Strain V	0.5 × 1.0	White	−	+	−	−	+	¶	−	+	+	−	−	+	Mud, water.
Bacterium chitinochroma	0.5 × 1.2	Yellow	−	+	−	+	+	−	−	+	+	−	−	−	Sand, water, intestines of squid.

Basic liquid medium: moderate growth, sometimes with formation of ring or pellicle. Scant granular sediment.

Sea water gelatin: liquefaction, growth absent in stab but abundant in liquefied zone.

Does not hydrolyze starch nor produce hydrogen sulfide. Four of five strains reduce nitrates. The strains vary in their ability to ferment sugars. All are unable to digest cellulose.

Aerobic.

Optimum temperature 20° C.

Habitat: Common in marine sand, mud and water. Also isolated from the shell of a decomposing horseshoe crab, *Limulus polyphemus*, and from the intestinal tract of *Venus mercenaria mercenaria*, *Ovalipes ocellatus ocellatus*, *Mustelus mustelus* and *Spheroides maculatus*.

Bacterium chitinochroma, n. sp.

Short rods, .45 to .75 by .90 to 1.4 microns in size. Gram negative. Motile.

Basic agar plate: colonies circular, smooth, entire, raised, varying in color from lemon to deep orange.

Basic liquid medium: abundant growth with production of pellicle. Scant granular sediment increasing with age of culture.

Sea water gelatin: active liquefaction, no growth in stab, but thick bright yellow growth throughout the liquefied zone.

Does not reduce nitrates: hydrolyzes starch: does not produce hydrogen sulfide, ferments dextrose and sucrose, but not lactose, glycerol and mannitol. Does not digest cellulose.

Aerobic.

Optimum temperature 20° C.

Habitat: marine sand, mud, and water. Also isolated from the intestinal tract of the squid, *Loligo pealeii pealeii*. Common occurrence.

The characteristics of the bacteria are summarized in Table I.

SUMMARY

Bacteria capable of decomposing chitin were isolated from sea water, marine sand and mud, and the intestinal contents of several marine animals.

Two species of marine chitin-decomposing bacteria are described. All of the bacteria are Gram negative, asporogenous, motile, short rods. Ammonia, reducing substances, and organic acids are readily demonstrable products resulting from the decomposition of purified chitin by pure cultures of the bacteria.

These bacteria decompose chitin not only in purified preparations but also in natural chitinous material such as horseshoe crab shell.

The writer is indebted to Dr. S. A. Waksman for suggestions in carrying out the investigation and in preparing the manuscript.

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TABLE FOR DENSITY OF SEA WATER AT 0° C. AND ATMOSPHERIC PRESSURE FOR VALUES OF CHLORINITY BETWEEN 18.00 AND 20.99 ACCORDING TO KNUDSEN'S FORMULA

By

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It is customary to express the density of sea water at atmospheric pressure,

$$1 + \sigma_t \cdot 10^{-3},$$

in terms of σ_t to two decimal places. This is usually computed from chlorinity and temperature by means of the Hydrographical Tables (Knudsen, 1901), which give it as the difference of two terms:

$$\sigma_t = \sigma_0 - D.$$

σ_0 is given as a function of chlorinity alone, the density of sea water at 0° C. and atmospheric pressure being

$$1 + \sigma_0 \cdot 10^{-3},$$

and D is tabulated as a function of σ_0 and temperature. While D is tabulated to three decimal places, σ_0 is given to only two decimal places in the Tables, so their use is a departure from the common rule that calculations be executed to at least one more significant figure than the result.

Of course there is necessarily an uncertainty in the second decimal place of σ_t due to the uncertainty in chlorinity and temperature as commonly measured. This probably produces an error in σ_t which very often amounts to 0.01 and occasionally to even 0.03. Nevertheless this is no reason to introduce a further uncertainty due merely to calculation. This is especially true in deep water, where the second decimal place may assume great importance so that its highest accuracy in keeping with convenience is desirable. If σ_0 and D are known exactly to the second decimal place only, the resulting value of σ_t may be in error by as much as 0.010 and the chances are one in four that it is not correct in the second decimal place. Furthermore chlorinity is sometimes determined to some significance in the third

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decimal place (of ‰), and this cannot be adequately converted to σ_0 when the latter is tabulated to two decimal places only.

In order to eliminate largely this error of calculation we have formed the accompanying table giving σ_0 to three decimal places for the range of chlorinity from 18.00 to 20.99‰, which fully covers the waters found in the open ocean. It was computed from Knudsen's formula[2] relating σ_0 to chlorinity in parts per thousand,

$$\sigma_0 = -0.069 + 1.4708\,Cl - 0.001570\,Cl^2 + 0.0000398\,Cl^3.$$

In regard to the accuracy of the formula it is first to be noted that, even if the coefficients are exact in the last figure given, a maximum error in σ_0 of 0.0021 at chlorinity 20‰ might result because the subsequent figures are unknown. The coefficients were derived by Knudsen (1902, p. 157) from 22 selected samples for which the chlorinity and density were carefully determined. The average magnitude of the deviations of the σ_0 values from the formula is 0.0047; this was assigned chiefly to errors in the chlorinity determinations. The chlorinity values used by Knudsen, according to the old definition of chlorinity (Sørensen, 1902, p. 137) but using 1938 atomic weights, need to be increased by a factor 1.00048, the standard water of supposed chlorinity 19.380‰ having an actual value 0.0094‰ greater as given by Jacobsen and Knudsen (1940, p. 22). In order to obviate this discrepancy they have redefined chlorinity as 0.3285234 times the mass of silver necessary to precipitate the halogens in unit mass of sea water, and the formula for σ_0 is appropriate when chlorinity is thus defined.

A check on the formula at one point was obtained by the precise analysis of the Urnormal 1937 water. This sample of natural sea water was found to have a chlorinity of 19.381‰ and $\sigma_0 = 28.137$, the latter agreeing exactly with the formula (Jacobsen and Knudsen, 1940, p. 38). The conclusion indicated is that within the range of the accompanying table the third decimal place of σ_0 as given by the formula is doubtful but at the same time definitely significant even in absolute value. Of course it is assumed implicitly in the formula that variations in concentration of other dissolved substances relative to chlorine are too small to make the third decimal place of σ_0 insignificant. While this is justified for the samples Knudsen worked with, no sufficiently extended study has been made to ensure that the simple formula holds for all ocean waters to this degree of accuracy.

[2] Each value before rounding off to three decimal places was found to agree with the Hydrographical Tables with the exception of chlorinity 18.94‰, for which he gives $\sigma_0 = 27.49$, the formula giving 27.4952.

In regard to the values of D in the Hydrographical Tables, Knudsen (1902, p. 172) points out that linear interpolation may lead to an error as great as 0.002, but that the tabulated values are fully exact in the third decimal place. It is however doubtful that sufficiently diversified samples of sea water were investigated to be sure of this statement.

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TABLE OF σ_0 AS FUNCTION OF CHLORINITY

Cl,°/₀₀	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
18.0	26.129	143	158	172	187	201	216	231	245	260
18.1	26.274	289	303	318	332	347	361	376	390	405
18.2	26.419	434	449	463	478	492	507	521	536	550
18.3	26.565	579	594	608	623	637	652	667	681	696
18.4	26.710	725	739	754	768	783	797	812	826	841
18.5	26.855	870	885	899	914	928	943	957	972	986
18.6	27.001	015	030	044	059	074	088	103	117	132
18.7	27.146	161	175	190	204	219	233	248	263	277
18.8	27.292	306	321	335	350	364	379	393	408	422
18.9	27.437	452	466	481	495	510	524	539	553	568
19.0	27.582	597	612	626	641	655	670	684	699	713
19.1	27.728	742	757	771	786	801	815	830	844	859
19.2	27.873	888	902	917	931	946	961	975	990	*004
19.3	28.019	033	048	062	077	091	106	121	135	150
19.4	28.164	179	193	208	222	237	252	266	281	295
19.5	28.310	324	339	353	368	382	397	412	426	441
19.6	28.455	470	484	499	513	528	543	557	572	586
19.7	28.601	615	630	644	659	674	688	703	717	732
19.8	28.746	761	775	790	804	819	834	848	863	877
19.9	28.892	906	921	936	950	965	979	994	*008	*023
20.0	29.037	052	067	081	096	110	125	139	154	168
20.1	29.183	198	212	227	241	256	270	285	299	314
20.2	29.329	343	358	372	387	401	416	431	445	460
20.3	29.474	489	503	518	532	547	562	576	591	605
20.4	29.620	634	649	663	678	693	707	722	736	751
20.5	29.765	780	795	809	824	838	853	867	882	897
20.6	29.911	926	940	955	969	984	999	*013	*028	*042
20.7	30.057	071	086	101	115	130	144	159	173	188
20.8	30.203	217	232	246	261	275	290	305	319	334
20.9	30.348	363	377	392	407	421	436	450	465	479

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SUMMARY OF SOME RESULTS OF INTERNAL-WAVE INVESTIGATIONS IN THE NORTH ATLANTIC

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(Contribution No. 276, Woods Hole Oceanographic Institution)

Observations at 13 anchor-stations occupied by Atlantis within recent years have substantiated Helland-Hanson's earlier suggestion that short-period vertical oscillations of the water-layers cause significant time-variations of oceanographic properties throughout the ocean space. And, hence, occasional vertical series of oceanographic observations may not necessarily represent average conditions at the locality sampled.

Measurements of vertical oscillations of the water-layers of the deep ocean were obtained from temperature- and salinity-samplings, repeated as rapidly as possible over periods ranging from 27 to more than 300 hours, at 17 levels, between surface and 1,200 to 1,300 meters. Since the localities selected for study were characterized by gently sloping isopycnal surfaces, the corrected observations when plotted as time-series clearly show the vertical displacements.

A recent analysis of conditions at an Atlantis station in the southern North Atlantic (Station 3245 in 25° 32' north and 53° 45' west) comprised materials from 28 repeated samplings of the water-column at 17 levels between surface and 1,100 meters, obtained during an approximate 26-hour period ($02^h\ 54^m$ GMT, January 23, to $04^h\ 45^m$ January 24, 1939) while the vessel was anchored at a depth of 5,000 meters. During this time temperature at standard depths ranged from 0°.32 to 2°.25 because of vertical displacements of the water-particles. The smaller variations (0°.32 to 0°.36) occurred where the water-column was least thermally stratified and where vertical displacements were largest (48 to 56 meters), whereas larger variations (1°.31 to 2°.25) occurred at depths characterized by an increased vertical temperature- (and density-) stratification. Relationships between vertical density- and temperature-distributions, vertical displace-

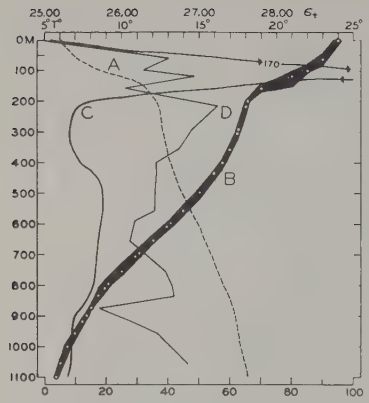

Fig. 1--Atlantis Station 3245: $02^h\ 54^m$, January 23 to $04^h\ 45^m$, January 24, 1939 (GMT) [A = average vertical distribution of density (σ_t); B = average vertical distribution of temperature, variation at fixed depths indicated by width of ribbon; C = average vertical rate of change of density per meter, $\Delta\ \sigma_t/\Delta Z$; D = vertical displacements of water-column during observation-period (referred to bottom scale, meters)]

ments and temperature-variations, and vertical rate of change of density at Station 3245 are illustrated by Figure 1.

Analytical transformation of the observational materials by harmonic analysis of vertical displacements of 22 selected isotherms (23° to 6°), and subsequent statistical treatment, revealed that for the observation-period the oscillations could be suitably represented by combinations of two sine-waves having periods of 12 and 24 lunar hours. The coefficients, tabulated in Table 1, have had phases adjusted to refer from $13^h\ 32^m.3$, January 22, 1939 (GMT), the time of the Moon's upper transit at the Greenwich meridian, but are not to be construed as being valid outside the observation-period. Adequacy of the empirical representation is manifested by the residues, resulting after subtraction of the two sine-waves from observed displacements, forming a random distribution.

Within the water-column, vertical variations of phases, amplitudes, and ratios of amplitudes are identified with its structure (Fig. 1, Table 1). In the upper strongly stratified layers, between approximately 50 and 150 meters, phases changed rapidly with depth and amplitudes were relatively small with the semidiurnal dominating. Somewhat deeper, in less-stratified water, as between 150 and 450 meters, phases were more uniform and amplitudes attained maximum values with the semidiurnal again dominating. In still deeper water of increased stability, as between 550 and 1,050 meters, vertical variations of phase-angles increased, amplitudes in general decreased, and the diurnal wave usually dominated. For 19 of the 22 vertical displacements studied, semidiurnal and diurnal maxima occurred within three hours of each other, and for 14 of the 22 cases semidiurnal amplitudes were greater (Table 1); dominance being particularly striking in depths less than 700 meters. Throughout the water-column (to 1,050 meters' depth) the range of amplitude-ratios [(semidiurnal/diurnal) = 8.00 to 0.185] was approximately the same as the range of ratios computed from tidal harmonic constants at shallow-water tidal stations encircling

Table 1

Isotherm	C_o	C_{24}	α_{24}	C_{12}	α_{12}	(C_{24}/C_{12})
23.0	62.52	5.39	23.39^h	5.56	7.08^h	0.97
22.0	99.28	4.56	22.56^h	5.09	7.71^h	0.90
21.0	118.74	0.84	7.50^h	6.72	8.45^h	0.125
20.0	135.11	0.94	11.20^h	2.04	8.96^h	0.461
19.0	157.58	2.48	12.07^h	2.53	1.01^h	0.980
18.0	216.46	13.33	15.73^h	11.01	3.36^h	1.211
17.5	295.80	5.41	15.86^h	10.27	2.66^h	0.527
17.0	356.79	2.85	17.89^h	11.21	3.15^h	0.254
16.5	400.76	2.43	15.23^h	8.52	3.75^h	0.285
16.0	434.22	4.42	13.17^h	15.34	3.58^h	0.288
15.0	497.08	4.01	13.53^h	12.82	2.65^h	0.313
14.0	555.24	1.57	16.00^h	11.82	2.43^h	0.133
13.0	607.66	1.03	2.12^h	5.78	3.72^h	0.178
12.0	653.18	3.87	17.65^h	2.76	4.29^h	1.40
11.0	702.23	4.69	17.60^h	5.12	5.48^h	0.916
10.0	755.36	8.28	7.00^h	4.22	4.85^h	1.962
9.0	805.28	6.88	11.46^h	5.02	3.97^h	1.371
8.5	835.32	7.82	14.53^h	3.33	4.92^h	2.348
8.0	875.05	2.79	21.44^h	1.21	2.58^h	2.306
7.5	918.95	6.54	0.76^h	1.21	3.64^h	5.405
7.0	956.95	4.24	21.03^h	9.36	11.16^h	0.453
6.0	1057.45	11.87	22.58^h	8.24	11.53^h	1.44

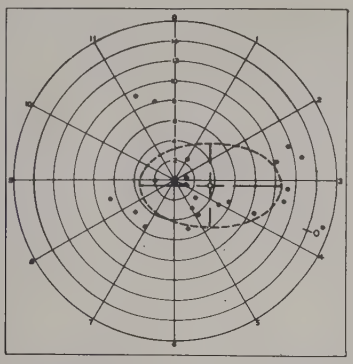

Fig. 2--Harmonic dial for 12-lunar-hour sine-waves in vertical displacements of 22 isotherms at Atlantis Station 3245

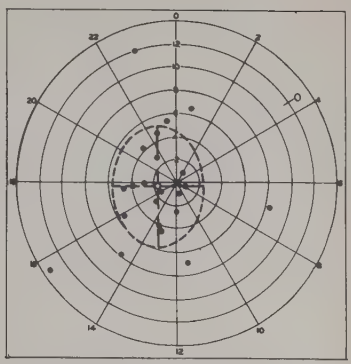

Fig. 3--Harmonic dial for 24-lunar-hour sine-waves in vertical displacements of 22 isotherms at Atlantis Station 3245

[Scale refers from Moon's upper transit at Greenwich ($13^h\ 32^m$, January 22, 1939), and inner 0 indicates Moon's upper transit at meridian of Station 3245 ($17^h\ 14^m$, January 22, 1939, GMT); each dot marks an isotherm, length of vector from center gives amplitude (in meters) and its direction, the phase in lunar hours]

Station 3245 (6.414 at Tybee Island Light in 32° 02' north and 80° 51' west and 0.252 at St. Thomas Island in 18° 20' north and 64° 56' west).

Statistical analyses of the coefficients of the two sine-waves were undertaken to obtain information concerning space-variability and average properties of the oscillations. Methods similar to those developed by Bartels for time-series analysis of other geophysical data were employed. In Figures 2 and 3, coefficients of the lunar diurnal and semidiurnal waves for the 22 isotherms (Table 1) are plotted in polar coordinates; each coefficient is represented by a single dot, its amplitude being given by distance from the center of the dial and its phase by direction. The mass-centers of the two groups of points represent properties of the average sine-waves, and the 50 per cent "probability-ellipses" were computed as suitable expressions for the scatterings. Geometric properties of the two groups of points as indicated by ellipticity, rotation of the ellipse, relative scattering, relative variability in distribution of amplitude and phase, etc., as well as average properties of the two frequencies, furnish a basis for comparison of conditions observed at various localities. The statistical constants involved may always be computed and are representative of the Gaussian distributions best fitting the groups of points. The results are treated with that proverbial "grain of salt" necessary in all applications of probability-theory.

Distinctions in geometric properties of lunar diurnal and semidiurnal groups of points are illustrated by the ellipse constants tabulated in Table 2. In this Table values under the heading "isotherms" were computed from harmonic constants derived from vertical oscillations of 22 isotherms (Table 1) whereas those under the heading "standard depths" were derived from phase- and amplitude-relations at forty-three 25-meter intervals between surface and 1,050 meters. Both sets of values are essentially the same, and reality of the average properties has been statistically demonstrated.

Table 2

Item	Isotherms		Standard depths	
	12^h	24^h	12^h	24^h
Major axis, P_1	7.0643	5.2591	6.8339	5.1528
Minor axis, P_2	4.2053	3.8749	4.1272	3.5638
Ratio (P_1/P_2)	1.6799	1.3572	1.6558	1.4459
Direction P_1	3^h	12^h	3^h	12^h
Dispersion	6.983	5.548	6.781	5.321
Average vector: Length	.....	.....	4.38	2.21
Phase	.....	.....	$2^h.97$	$17^h.17$

Both groups of points possessed marked ellipticities indicating that the small average amplitudes (Table 2) resulted from combination of larger amplitudes but of nearly opposite phase. The semidiurnal coefficients had the most marked ellipticity, largest average amplitudes, and greatest amounts of scattering. Directions of the major axes of the ellipses differed by 90°, being 03^h for the semidiurnal, 12^h for the di-

Table 3

Item	Lunar semidiurnal	Lunar diurnal
Major axis, P_1	10.8233	1.9732
Minor axis, P_2	3.0022	0.9583
Ellipticity (P_1/P_2)	3.6051	2.059
Direction P_1	2^h3	12^h0
Dispersion	9.534	1.860
Average vector: Length	2.604	1.380

urnal, and that for the semidiurnal cloud nearly coincided with the phase of its average vector as compared with a five-hour difference for the diurnal cloud.

Positions of the axes of the ellipse indicate greater variability for phase-angles than amplitudes (Figs. 2 and 3). For the 12-hour point aggregate the major axis end-points corresponded to amplitudes of 3.6 and 10.7 meters and to phase-angles of 93° and 261°, and the minor axis end-points to 5.1 and 5.9 meters and to phase-angles of 44° and 143°. For the 24-hour point aggregate the major axis end-points corresponded to amplitudes of 5.2 and 5.8 meters and to phase-angles of 196° and 342°, and the minor axis end-points to 2.4 and 5.6 meters and to 98° and 267°.

Certain consequences of the analysis are brought out by consideration of results of a similar treatment of theoretical vertical displacements at Station 3245 as computed according to Fjeldstad's internal-wave theory. The possible internal waves (relative values only) corresponding to a given, continuously varying density-distribution (as at Station 3245) may theoretically be computed by numerical integration of a second-order differential equation, and although an infinite number of solutions, corresponding to an infinite number of internal waves, are possible, practical consideration limits computations to the first four. Absolute theoretical values, obtained by a least-square fitting of the combined relative displacements to observed phases and amplitudes, were subjected to the same statistical treatment as the observed values. The results suggest that, regardless of irregular influences, good representation of observed conditions is obtained from the theoretical internal-wave considerations of Fjeldstad. Statistical distinctions between diurnal and semidiurnal point aggregates are concordant with those existing between the two groups of coefficients computed directly from observations (Tables 2 and 3). Thus the major axis, P_1, the ellipticity, (P_1/P_2), the average vector, and the dispersion of the theoretical semidiurnal point aggregate exceed similar characteristics of the diurnal. Likewise, the major axis of the theoretical diurnal ellipse is, like the observed, in a direction clockwise from that of the semidiurnal ellipse--possible values being 2.32 hours for the semidiurnal and 12 hours for the diurnal.

Comparison of properties of theoretical and observed semidiurnal coefficients shows, as the most striking feature, an increased ellipticity of the former from (P_1/P_2) = 1.68 to (P_1/P_2) = 3.61 (major axis increased 53 per cent and minor axis diminished 29 per cent), illustrating that theoretical semidiurnal wave-motions of the water-column would be of more nearly opposite phases. The absolute scattering of the points increased from 6.983 to 9.534 for the theoretical aggregate and the major-axis direction of the theoretical ellipse with a possible value of 2.32 hours is not greatly different from the 3-hour value computed for the observed coefficients.

Comparison of the two groups of diurnal coefficients reveals ellipticity of the theoretical values increased from (P_1/P_2) = 1.36 to (P_1/P_2) = 2.06. The absolute scattering of the points diminished from 5.55 for the observed to 1.86 for the theoretical group and rotations of both ellipses appear identical, directions of both major axes being 12 hours.

Consideration of phases and amplitudes of the average sine-waves characterizing the observed vertical oscillations of the water-layers between surface and 1,050 meters suggest the possibility of a connection between internal-wave and tidal mechanisms. These average properties, demonstrated to be statistically significant, as given by Table 2, show a phase-difference (diurnal minus semidiurnal) of 2.2 lunar hours and an amplitude-ratio (semidiurnal/diurnal) of 1.98. The former is not greatly different from the phase-difference of approximately 3.5 hours between semidiurnal and diurnal tides at the geographical position of Station 3245 (as given by the cotidal charts of R. Sterneck) and the latter lies within the range of ratios of semidiurnal to diurnal amplitudes of 2.98 to 0.25 computed from tidal harmonic constants for the not too distant West Indian Waters.

Since tidal observations have been entirely restricted to the comparatively shallow portions of the sea, actual conditions in the deep waters are unknown. Consequently, endeavors to link up tidal and internal-wave mechanisms need be dealt with cautiously. However, in view of the general support given to this conception by the present, as well as other methodical investigations, there is strong indication of relationship between tidal and internal-wave mechanisms, although, as pointed out by Helland-Hansen years ago, the question of how the tidal wave can produce vertical movements of the dimensions observed in the different strata of the sea is at present inexplicable.

Table 4

Internal-wave order	Propagation velocities, cm sec^{-1}		
	Station 3245	Station 3091	Station M.S. - 68
1	259	276	267
2	110	87	90
3	80	70	75
4	54	50	49

Propagation-velocities of the first four internal waves at Station 3245, as computed from Fjeldstad's equation, range from 259 to 54 cm/sec, the velocity-diminution with increasing order being an approximate harmonic progression. These values agree fairly well with similar results from two widely separated locations in the North Atlantic of approximately the same depth (about 5,000 meters); one computation having been made by Fjeldstad (Michael Sars 68) at a position 39° north in 51° west, and the other by this writer for a station (Atlantis 3091) about 110 miles northwest of Bermuda (Table 4). As a tentative result, fair approximation to the propagation-velocities, C_n, of the internal waves in the open ocean is given by

$$C_n \text{ in (cm/sec)} = 221/N$$

N being the order of the wave. Discrepancies in this empirical representation chiefly affect the first two orders; from information at hand, differences for higher orders appear irrevelant. Reduction in propagation-velocities occurs in the less deep waters; for a station of 580 meters' depth in the Faero Shetland Channel (Michael Sars 115) approximation to propagation-velocities of the internal waves given by Fjeldstad is

$$C_n \text{ in (cm/sec)} = 78/N$$

The length of the first-order internal wave characterizing the open Atlantic may be taken as approximately 100 km, or about 1/100 the length of the semidiurnal tidal wave at the mean depth of the oceans. Likewise, the ratio of length of the first-order internal wave to the mean depth of the oceans is of the order of magnitude of 10^{-2} whereas that for the semidiurnal tidal wave is 10^{-4}.

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SEA LEVEL DIFFERENCE BETWEEN KEY WEST AND MIAMI, FLORIDA

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In a previous paper (Montgomery, 1938, p. 177) it was suggested that fluctuations in the drop in sea level from Key West to Miami might indicate fluctuations in strength of the Florida Current. Both stations are located on the left side of the Straits of Florida, Key West near the entrance and Miami 130 nautical miles down the shore at the most constricted section, where it is supposed that the Florida Current runs swiftest. The acceleration of the water on approaching the constriction is accompanied by a decrease in head. In that paper it was assumed that the drop in sea level from Key West to Miami represents the total head, in other words that Key West indicates the level of the current starting practically at rest. Not knowing the absolute difference in sea level between the two stations, it was assumed to be 19 cm, the value obtained by leveling between Cedar Keys and St. Augustine. These two assumptions were in good agreement.

It was however quite fallacious to assume the water relatively motionless at the Key West section. According to Pillsbury's (1890, p. 608) measurements from the *Blake* the surface speed at the axis of the Florida Current on a section about 40 miles west of Key West is 2.24 knots, and on the Miami section it is 3.46 knots, or 115 cm sec^{-1} and 178 cm sec^{-1} respectively. From the relationship between velocity v, head h and acceleration of gravity g,

$$v_2^2 - v_1^2 = 2\ g\ (h_1 - h_2),$$

the drop in head corresponding to this velocity increase would be 9.4 cm. The expected drop from a section at Key West instead of from the *Blake* section might be three quarters of this or 7.0 cm.

Tables I and II give for Key West and Miami the monthly departures from normal of sea level reduced to normal atmospheric pressure, or the departures from normal of total head at a fixed level sufficiently low never to be exposed by the tide. These are revisions to date of the previous tables (Montgomery, 1938, Tables 2,

[1] Contribution No. 277.

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4). The headings give details of the normals used. Monthly values of sea level were kindly supplied by the Director of the Coast and Geodetic Survey. All except the values for 1939 have been published by the Association d'Océanographie Physique (1939, 1940a, 1940b). The original values are in hundredths of feet, and the original values of pressure in hundredths of inches of mercury. If there is no error in the last place of the original values, the maximum error of the monthly values tabulated here is thus 0.425 cm. The mean monthly values from the two tables are plotted in Figure 4.

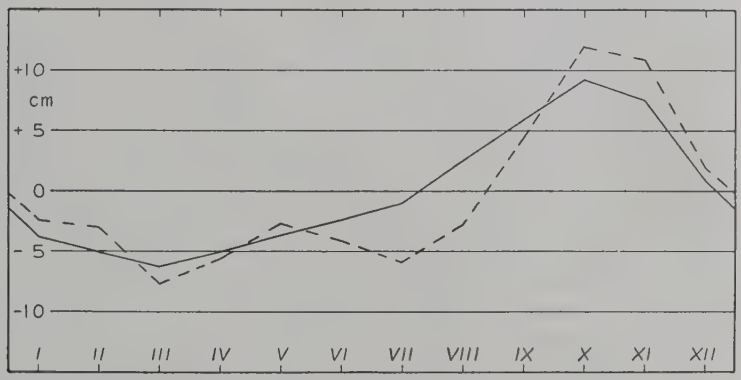

Figure 4. Annual variation of sea level reduced to normal atmospheric pressure: full line for Key West 1913–1939, broken line for Miami 1931–1939.

In March, 1934, a leveling survey was made between Miami and Key West. Key West Bench Mark 29 was 66.23 cm higher than Miami Bench Mark 6, the probable error being less than 1 cm, as stated in a communication from the Director of the Coast and Geodetic Survey.[2] Accordingly the zero on the tide staff was 42.9 cm lower at Key West than at Miami, and the normal staff reading

[2] "The probable accidental error of the first-order leveling between these two marks, computed according to the formula adopted by the International Geodetic Association in 1912, is 0.275 mm. per km. Thus, for the whole 265 kilometers between Tidal 6 (USE) and Tidal 29 the probable accidental error is 4.5 mm. The probable systematic error is of an order of size of 0.01 mm. per km. In view of the above, it would seem reasonable to assume that the probable error of the observed difference is less than one centimeter. The actual error cannot be computed, but the chances are good that it does not exceed an inch or an inch and a half."

was 3.1 cm higher at Key West. Taking into account the difference in normal atmospheric pressure at the two stations it is found that for zero departure of sea level and of pressure the head was 2.4 cm greater at Key West than at Miami.

Table III gives monthly values of the drop in head from Key West to Miami. It is to be noticed that March, 1934, is a nearly normal March, that 1934 is a nearly normal year, and that there is no secular change of the yearly values, thus giving no evidence of a vertical shift of the tide staffs from their relative positions as determined in March, 1934.

The mean value for the 8-year period of the drop in head from Key West to Miami is found to be 4.9 cm, considerably less than the value found to correspond with the increase in velocity of the Florida Current. It is possible that errors in the velocity determinations, in the leveling and in the determinations of sea level could account for this discrepancy. The drop in head of 4.9 cm would correspond to a velocity increase from 149 cm sec^{-1} to 178 cm sec^{-1}.

The variation of the individual monthly values in Table III and even the annual variation are greater than the supposed variation in increased velocity of the current from Key West to Miami. Certainly they cannot correspond at all directly to the total velocity of the current. There are even a few negative values in the table. Most of the discrepancy is probably due to the effect of local winds on the sea level at the two tidal stations.

Perhaps an extensive investigation of the wind effect would make its elimination from the sea level observations possible. At the present time however there is no justification for using the difference in sea level from Key West to Miami as an indication of the strength of the Florida Current.

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TABLE I

DEPARTURE FROM NORMAL IN CENTIMETERS OF MONTHLY SEA LEVEL AT KEY WEST REDUCED TO SEA LEVEL PRESSURE OF 30.02 INCHES

(Normal sea level is the average for 1913–1939, being staff reading of 4.95 feet; zero on staff is 13.06 feet below Bench Mark 29)

Month	*I*	*II*	*III*	*IV*	*V*	*VI*	*VII*	*VIII*	*IX*	*X*	*XI*	*XII*	*Year*
1913	− 5.0	− 2.6	− 5.8	− 1.4	− 1.9	+ 1.4	− 0.2	+ 6.3	+ 5.4	+ 6.7	+ 3.0	− 1.8	+ 0.3
1914	− 5.9	− 9.8	−12.0	− 8.5	+ 5.4	+ 0.6	− 4.9	+ 7.7	+ 9.7	+ 0.9	+ 1.7	+ 1.6	− 1.1
1915	− 2.2	− 2.8	− 5.2	− 5.8	−10.5	− 6.3	− 4.0	− 1.7	+ 7.3	+ 7.9	+ 5.1	− 4.0	− 1.8
1916	− 3.6	− 3.1	−10.5	− 7.8	− 2.4	− 8.2	− 1.3	+ 1.5	+ 5.6	+12.8	+10.3	− 0.4	− 0.6
1917	− 8.2	− 4.9	+ 7.6	+ 1.7	− 1.9	− 3.1	− 5.2	− 5.9	+ 8.1	+15.7	+17.9	+ 7.3	+ 2.4
1918	− 6.0	−10.2	− 6.0	− 1.0	0.0	− 5.0	− 2.3	+ 1.4	+ 3.0	+ 0.9	+ 4.8	+ 3.7	− 1.4
1919	− 6.7	−12.0	− 4.7	− 8.3	− 9.0	− 2.6	+ 0.1	+ 1.7	+ 5.7	+11.8	+ 7.6	+ 0.7	− 1.3
1920	− 8.9	− 6.9	−19.1	−12.9	− 8.8	− 1.6	+ 0.1	− 0.6	+ 3.8	+ 6.7	+ 4.3	− 1.2	− 3.8
1921	− 2.2	− 6.1	− 3.8	− 0.6	− 2.0	+ 3.5	− 0.2	+ 1.3	+ 9.9	+10.8	+ 2.6	− 0.3	+ 1.1
1922	− 6.7	− 1.0	− 2.0	− 3.6	− 4.5	− 0.7	+ 3.6	+ 2.1	+ 7.8	+ 5.6	+ 2.8	− 5.2	− 0.2
1923	− 4.5	− 5.4	− 2.9	− 2.9	− 0.9	− 2.3	− 5.0	− 4.6	+ 1.6	+ 3.5	+ 1.4	− 7.4	− 2.5
1924	− 6.0	− 4.4	− 8.4	−14.8	−11.5	− 5.2	+ 1.1	+ 4.0	+ 5.6	+ 7.6	+ 7.3	−10.1	− 2.9
1925	− 8.3	− 4.6	− 7.0	−15.1	− 4.9	− 4.5	− 3.3	+ 3.1	+ 5.2	+ 4.5	+ 9.8	+ 0.5	− 2.0
1926	−10.2	−16.6	−15.3	− 8.8	− 8.7	− 6.3	− 5.8	+ 5.2	+ 7.2	+ 9.7	+ 4.0	− 2.7	− 4.0
1927	− 0.5	− 2.2	− 1.8	− 3.4	− 4.3	− 1.9	− 4.2	+ 2.2	+ 0.1	+ 6.2	+11.5	+ 3.5	+ 0.4
1928	− 4.8	−16.0	−11.0	−12.2	− 6.3	− 2.6	+ 0.3	+ 3.6	+ 4.8	+ 9.1	+ 9.0	+ 4.9	− 1.8
1929	− 8.3	− 2.4	− 7.1	− 1.5	− 2.0	− 2.7	+ 2.4	+ 2.5	+ 3.0	+ 3.1	+ 1.0	+ 1.9	− 0.8
1930	+ 3.2	+ 1.0	− 5.5	− 3.0	− 2.0	− 4.5	− 0.8	+ 5.4	+ 2.0	+ 8.0	+ 3.7	− 4.1	+ 0.3
1931	−11.3	− 9.8	− 5.0	− 5.0	−15.2	− 8.0	− 6.3	− 4.0	+ 3.1	+ 3.2	+ 5.0	+ 0.2	− 4.4
1932	− 0.3	− 6.9	− 9.9	− 6.9	− 4.4	− 4.8	− 1.2	+ 1.5	+ 5.6	+ 4.5	+ 9.1	+11.0	− 0.2
1933	− 0.4	− 2.7	− 8.1	− 2.4	+ 0.6	+ 3.7	+ 1.7	+ 6.0	+ 8.4	+17.1	+13.2	− 0.2	+ 3.1
1934	− 1.5	− 9.1	− 6.7	− 5.3	− 9.2	− 4.8	− 2.4	− 0.6	+ 8.6	+12.2	+ 7.6	+ 5.2	− 0.5
1935	+ 3.9	− 3.9	− 0.9	− 0.9	− 4.8	− 3.2	+ 0.9	+ 4.1	+ 0.5	+16.9	+11.9	+ 1.8	+ 2.2
1936	− 2.7	− 1.8	− 8.4	− 5.4	+ 4.8	+ 4.1	+ 3.7	+ 2.8	+10.7	+16.5	+11.4	+10.2	+ 3.8
1937	+ 4.8	+ 7.6	− 5.4	− 0.1	+ 5.5	− 1.0	+ 7.4	+11.1	+11.5	+16.1	+ 9.0	+ 3.6	+ 5.8
1938	− 1.0	+ 0.1	− 4.7	− 0.9	− 0.2	+ 1.2	− 1.5	+ 7.0	+ 4.5	+10.9	+13.7	+ 3.5	+ 2.7
1939	− 0.3	− 1.6	− 0.9	− 1.8	− 0.2	− 0.1	+ 0.2	+ 4.7	+ 9.6	+18.3	+14.1	+ 1.0	+ 3.6
Means	− 3.8	− 5.1	− 6.3	− 5.1	− 3.7	− 2.4	− 1.0	+ 2.5	+ 5.9	+ 9.2	+ 7.5	+ 0.9	—

TABLE II

DEPARTURE FROM NORMAL IN CENTIMETERS OF MONTHLY SEA LEVEL AT MIAMI REDUCED TO SEA LEVEL PRESSURE OF 30.04 INCHES

(Normal sea level is the average for 1932–1939, being staff reading of 3.44 feet; zero on staff is 9.48 feet below Bench Mark 6)

Month	*I*	*II*	*III*	*IV*	*V*	*VI*	*VII*	*VIII*	*IX*	*X*	*XI*	*XII*	*Year*
1931						− 9.5	−11.7	− 8.4	− 1.1	+ 1.6	− 0.2	− 4.3	
1932	− 4.7	− 8.0	−11.5	− 8.6	− 7.5	− 9.1	− 6.1	− 5.5	+ 7.0	− 0.3	+ 8.8	+ 9.9	− 3.0
1933	− 3.1	− 4.2	− 8.4	− 4.2	− 2.0	+ 0.1	− 5.2	− 1.2	+ 2.4	+18.7	+15.3	− 3.2	+ 0.4
1934	− 3.3	− 8.2	− 9.5	− 6.4	− 8.9	− 5.4	− 7.3	− 4.5	+ 2.9	+12.6	+ 6.8	+ 0.7	− 2.5
1935	+ 3.6	− 1.2	− 3.5	− 1.4	− 7.4	− 4.7	− 6.4	− 5.4	− 3.8	+15.5	+17.4	+ 3.6	+ 0.5
1936	− 3.8	− 2.1	−10.5	− 8.4	+ 6.1	+ 3.8	− 5.2	− 1.4	+ 8.9	+12.2	+ 8.3	+ 8.7	+ 1.4
1937	− 1.8	+ 5.2	− 4.8	− 5.0	+ 2.2	− 6.2	+ 0.1	+ 2.3	+ 7.0	+15.8	+ 6.8	+ 0.3	+ 1.8
1938	− 2.9	− 0.8	− 7.1	− 5.7	− 3.7	− 3.6	− 7.6	− 1.2	− 2.5	+13.7	+18.0	+ 4.4	+ 0.5
1939	− 3.0	− 4.5	− 6.1	− 5.2	− 0.5	− 2.4	− 3.6	− 0.2	+13.8	+18.0	+16.8	− 3.3	+ 1.7
Means	− 2.4	− 3.0	− 7.7	− 5.6	− 2.7	− 4.1	− 5.9	− 2.8	+ 4.4	+12.0	+10.9	+ 1.9	

TABLE III

SEA LEVEL DIFFERENCE IN CENTIMETERS, KEY WEST—MIAMI, ADJUSTED FOR ATMOSPHERIC PRESSURE
(2.4 cm plus values in Table I minus values in Table II)

	I	*II*	*III*	*IV*	*V*	*VI*	*VII*	*VIII*	*IX*	*X*	*XI*	*XII*	*Year*
1931						+ 3.9	+ 7.8	+ 6.8	+ 6.6	+ 4.0	+ 7.6	+ 6.9	
1932	+ 6.8	+ 3.5	+ 4.0	+ 4.1	+ 5.5	+ 6.7	+ 7.3	+ 9.4	+ 1.0	+ 7.2	+ 2.7	+ 3.5	+ 5.1
1933	+ 5.1	+ 3.9	+ 2.7	+ 4.2	+ 5.0	+ 6.0	+ 9.3	+ 9.6	+ 8.4	+ 0.8	+ 0.3	+ 5.4	+ 5.1
1934	+ 4.2	+ 1.5	+ 5.2	+ 3.5	+ 2.1	+ 3.0	+ 7.3	+ 6.3	+ 8.1	+ 2.0	+ 3.2	+ 6.9	+ 4.4
1935	+ 2.7	− 0.3	+ 5.0	+ 2.9	+ 5.0	+ 3.9	+ 9.7	+11.9	+ 6.7	+ 3.8	− 3.1	+ 0.6	+ 4.1
1936	+ 3.5	+ 2.7	+ 4.5	+ 5.4	+ 1.1	+ 2.7	+11.3	+ 6.6	+ 4.2	+ 6.7	+ 5.5	+ 3.9	+ 4.8
1937	+ 9.0	+ 4.8	+ 1.8	+ 7.3	+ 5.7	+ 7.6	+ 9.7	+11.2	+ 6.9	+ 2.7	+ 4.6	+ 5.7	+ 6.4
1938	+ 4.3	+ 3.3	+ 4.8	+ 7.2	+ 5.9	+ 7.2	+ 8.5	+10.6	+ 4.4	− 0.4	− 1.9	+ 1.5	+ 4.6
1939	+ 5.1	+ 5.3	+ 7.6	+ 5.8	+ 2.7	+ 4.7	+ 6.2	+ 7.3	− 1.8	+ 2.7	− 0.3	+ 6.7	+ 4.3
Means	+ 5.1	+ 3.1	+ 4.4	+ 5.0	+ 4.1	+ 5.1	+ 8.6	+ 8.9	+ 4.9	+ 3.3	+ 2.1	+ 4.6	+ 4.9

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THE EFFECT OF THE CIRCULATION OF WATER ON THE DISTRIBUTION OF THE CALANOID COMMUNITY IN THE GULF OF MAINE[1]

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Damas (1905) has pointed out that the flow of water tends to dissipate local populations of pelagic organisms, and that the permanence of breeding stocks may be maintained by the existence of eddies. His predictions have been strikingly confirmed by hydrographic observations in the Norwegian Sea (Sømme, 1933). Along the margins of the Gulf of Maine the permanence of the stock of *Sagitta elegans* is correlated with the stability of the hydrographic conditions which exist in different regions (Redfield and Beale, 1940). Walford (1938) has indicated the importance of fluctuations in the circulation on Georges Bank to the fate of haddock eggs spawned in that region. These studies and that of the author (1939) on the population of *Limacina retroversa* emphasize the rapidity with which currents move pelagic organisms about within the Gulf. It becomes a problem whether the community of the basin of the Gulf is truly endemic, and by what mechanism a breeding stock is maintained within the Gulf. Sømme (1934) has discussed this question in regard to the copepod population of the Lofoten area.

Bigelow (1926), who has described the zoöplankton of the Gulf in great detail, considers that the species which form the bulk of the pelagic population are endemic in origin, breeding with sufficient regularity and abundance to maintain the local stock by local reproduction. From its dominating member, *Calanus finmarchicus,* he has referred to the population as the calanoid community.

We have measured the catches taken in the Gulf during a year-round survey and will attempt to explain the distribution of numerical abundance in terms of the pattern of currents obtained during the period of observation.

Data

The data employed in the present study were collected in the course of cruises made by the research vessel "Atlantis" during the years of 1933 and 1934. The dates of these cruises and the numbers of the

[1] Contribution No. 281 from the Woods Hole Oceanographic Institution.

stations occupied are given in Table I. Thirteen cruises were made in the course of fifteen months, with the result that 684 hydrographic stations in the Gulf of Maine and its adjacent waters were occupied. At no time did a period longer than two months elapse without observation. The routine hydrographic and chemical data are published in the Bulletin Hydrographique (1933, 1934).

A supplementary cruise was made in May, 1936 in order to confirm certain observations made during the primary survey.

In the course of the cruises standard vertical hauls were made with a 1.5 meter Heligoland net of No. 0 silk having 38 meshes to the inch (Künne, 1933). The net was hauled from a point near the bottom to the surface at all stations occupied, weather permitting. This type of haul was selected in preference to the oblique haul in the belief that the procedure could be carried out uniformly as a part of the routine duties

TABLE I

Cruise No.	Dates	Stations	Number
16 and 17	June 19–July 10, 1933	1643–1721	79
21	Sept. 2–Sept. 14, 1933	1741–1802	62
22	Oct. 17–Oct. 29, 1933	1803–1860	58
23	Dec. 2–Dec. 11, 1933	1861–1906	46
24	Jan. 8–Jan. 13, 1934	1907–1934	28
26	Mar. 21–Mar. 29, 1934	2019–2070	52
27 and 28	Apr. 17–May 13, 1934	2071–2164	94
29	May 21–June 3, 1934	2165–2215	51
31	June 25–July 1, 1934	2217–2236	20
34	Aug. 10–Aug. 11, 1934	2252–2259	8
37	Sept. 17–Sept. 27, 1934	2268–2303	36
55	May 14–May 19, 1936	2555–2583	29

of the ship's company. Unfortunately, it proved impossible to use the net in rough weather, so that data are lacking from many stations, particularly those made in the winter months. The yields of the successful hauls have been measured by collecting the plankton on filter paper in a Buchner funnel. Suction was continued until the preserving fluid ceased to flow, whereupon the "dry" plankton was introduced into a measured volume of fluid and the resulting increase in volume noted. The data so obtained were reduced to figures expressing the number of cubic centimeters of "dry" plankton under each square meter of the sea surface. Before filtering and measuring collections, any large gelatinous organisms were removed (*Salpa*, ctenophores, medusae) with the result that the measurements reflect primarily the abundance of the crustacean community.

Since most of the hauls with which we are concerned were made in

FIG. 1. Volumes of zoöplankton taken in vertical hauls between September, 1933 and June, 1934. Numbers represent the cubic centimeters taken per square meter of sea surface. Contour interval 25, 50, 100, and 200 cc. per square meter.

depths greater than 100 meters, above which level most of the population may be expected to occur, these figures are thought to express the density of population more precisely than numbers reduced to unit volume of water strained. The general character of the results is not altered by expressing the catch in terms of the yield per cubic meter.

The determination of the "dry" volume of the catch by the method of filtration and displacement yields smaller values than are obtained by the "wet" method of allowing the animals to settle in a calibrated container. In order that our results may be compared with those of Bigelow and others who employed the settling method, a number of samples have been measured by both methods. The wet method gave values on the average 4.9 times higher than the dry method, the ratios

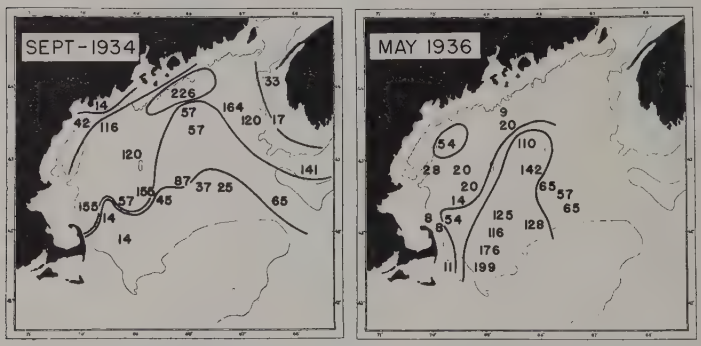

Fig. 2. Volumes of zoöplankton taken in vertical hauls in September, 1934 and May, 1936. Numbers represent the cubic centimeters taken per square meter of sea surface. Contour interval 50, 100, 200 cc. per square meter.

varying between 3.3 and 7. The ratio was smaller in the case of the larger samples, due perhaps to the tighter packing of large samples in the wet method and to the greater retention of water when large quantities of organisms are filtered off in the "dry" method.

The Seasonal Distribution of the Zoöplankton Population

The quantities of the catches obtained by vertical hauls, and their positions during the most complete periods of survey, are entered on the charts shown in Figs. 1 and 2. These charts show that the area of maximum abundance shifts its position with the season. From late summer until December the richest population is found in the northern portion of the Gulf, centering off Mount Desert. During the winter the center shifts to the west, coming to lie off the Massachusetts coast.

In late spring and early summer the richest catches were obtained along the southern margin of the Gulf, north of Georges Bank, extending from the offing of Cape Cod, eastward and northward toward the Bay of Fundy.

FIG. 3. Chart of the Gulf of Maine showing principal place names and the sectors into which the area is divided for analysis of population distribution. Contour encloses depths less than 100 meters.

In order to deal with the data statistically, the area of the Gulf has been divided into seven sectors as shown in Fig. 3. Each sector includes one of the principal lines of stations at which collections were regularly made. The quantities of plankton taken at each cruise in each sector have been averaged and the resulting number taken to represent the density of population in that sector at the time. While the data are frequently numerically inadequate, certain interesting regularities appear from its analysis.

Figure 4 shows the density of population in the various sectors at each principal period of survey. It presents graphically the shift in the center of population westward from the Mount Desert to the Massa-

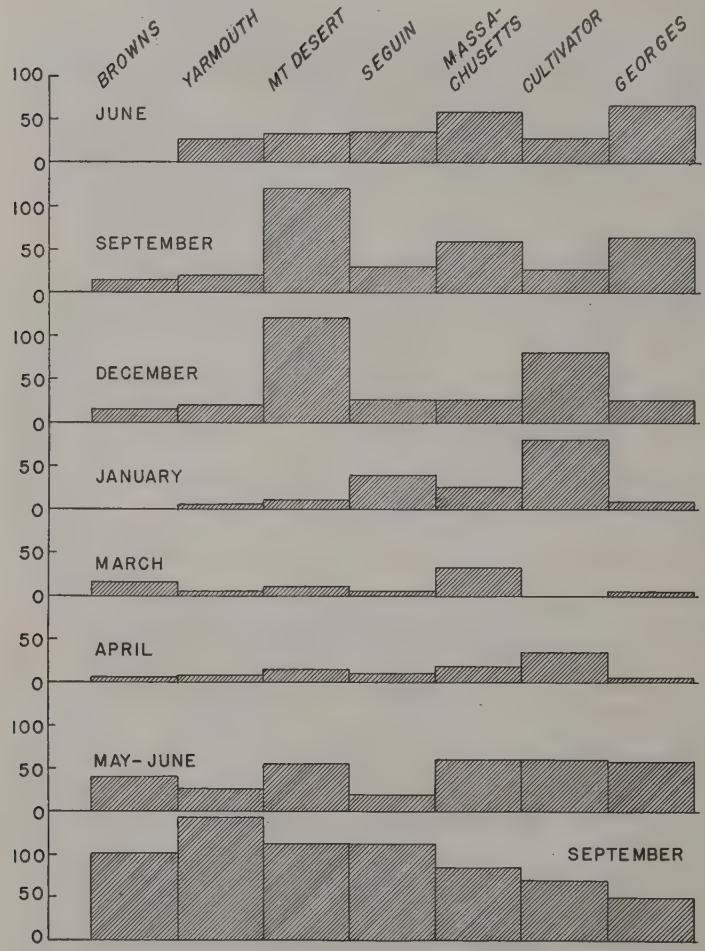

Fig. 4. The average catch in each sector of the Gulf of Maine during the period September, 1933 to September, 1934. Ordinates: cubic centimeters of zoöplankton per square meter of sea surface.

chusetts sector in the course of the winter and its extension along the southern sectors in May and June, followed by the reëstablishment of a maximal population in the northeastern sectors in September.

Figure 5 presents the same data in a form which brings out the sea-

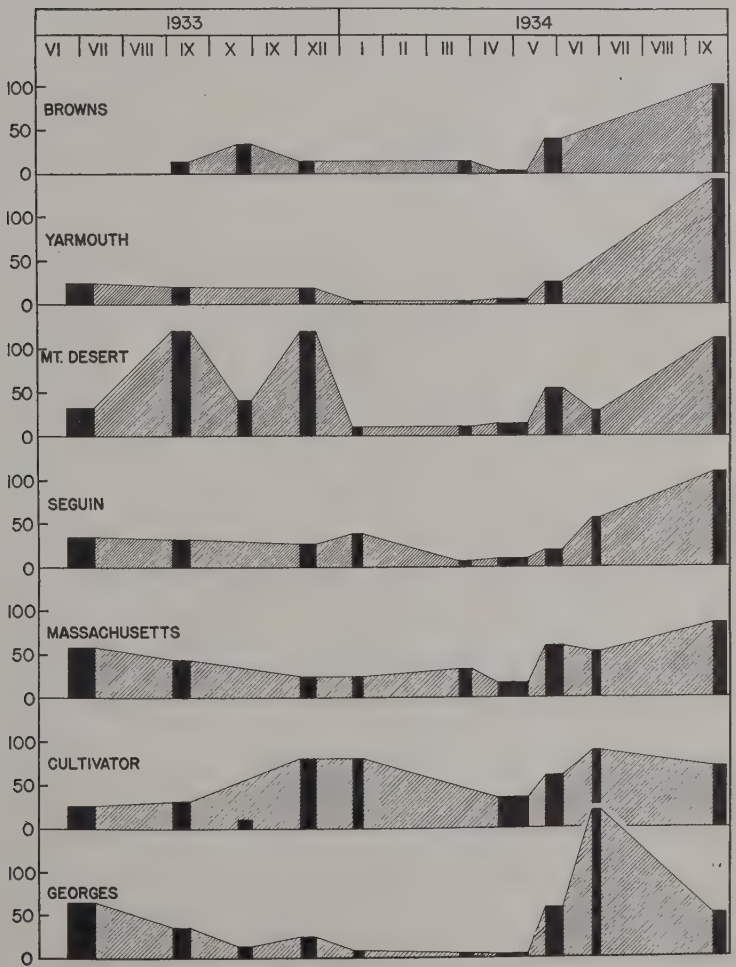

FIG. 5. Seasonal fluctuation of catch in each sector of the Gulf of Maine during the period June, 1933 to September, 1934. Ordinates: cubic centimeters of zoöplankton per square meter of sea surface. The black bars indicate the actual period occupied by each cruise.

sonal fluctuation in each sector. The sectors along the east and north sides of the Gulf are marked by a pronounced seasonal fluctuation—most extreme in the Mount Desert region. In contrast, the population is much more uniformly distributed from month to month in the Massachusetts and Cultivator sectors, which include the greater part of the western basin.

The general features of the distribution appear to recur from year to year, for our observations for September 1933 and 1934 show essentially similar patterns, as do also those for May–June, 1934 when compared with May, 1936. The seasonal distribution observed by Bigelow over a number of years is also in agreement. He found the quantitative fluctuations to be comparatively narrow from season to season in the waters of the western basin and considered the plankton in that part of the Gulf to be "rich" the year round. He reports the northern corner of the eastern basin, as well as the shallows off Cape Sable, to be the site of a wide seasonal fluctuation (Bigelow, 1926, p. 89).

The Circulation of the Gulf

The shift in the center of abundance of the zoöplankton population suggests that it is being borne about a great cyclonic eddy. We may consequently examine the nature of the circulation of the Gulf to see if it can account for the fluctuations in numbers in different places and to learn to what extent the calanoid community may be carried into and out of the Gulf by water movements.

The evidence marshalled by Bigelow (1927)—measurements with current meters, drift-bottles, temperatures, salinities, distribution of plankton, and dynamic calculations—can be harmonized with one type of dominant circulation only, a general anti-clockwise eddy around the basin of the Gulf. The demonstration of this, named by Huntsman (1924) and by Bigelow the "Maine" or "Gulf of Maine" eddy, with all it implies in its biological bearing, is perhaps the most interesting result of their joint explorations of the Gulf. Observations made during a series of years demonstrated that the center of the eddy shifted its precise location from summer to summer, and that marked seasonal variations in the circulatory scheme occurred. Observations of the velocity of the non-tidal drift of the surface made in shoal water about the margin of the Gulf indicated an average movement of seven miles per day, at which rate some three months would be required to complete the circuit of the eddy. No estimations were made of the velocity of the deeper layers.

The hydrographic data collected in the course of the cruises in 1933–34 have been analyzed by Dr. E. E. Watson, who has kindly per-

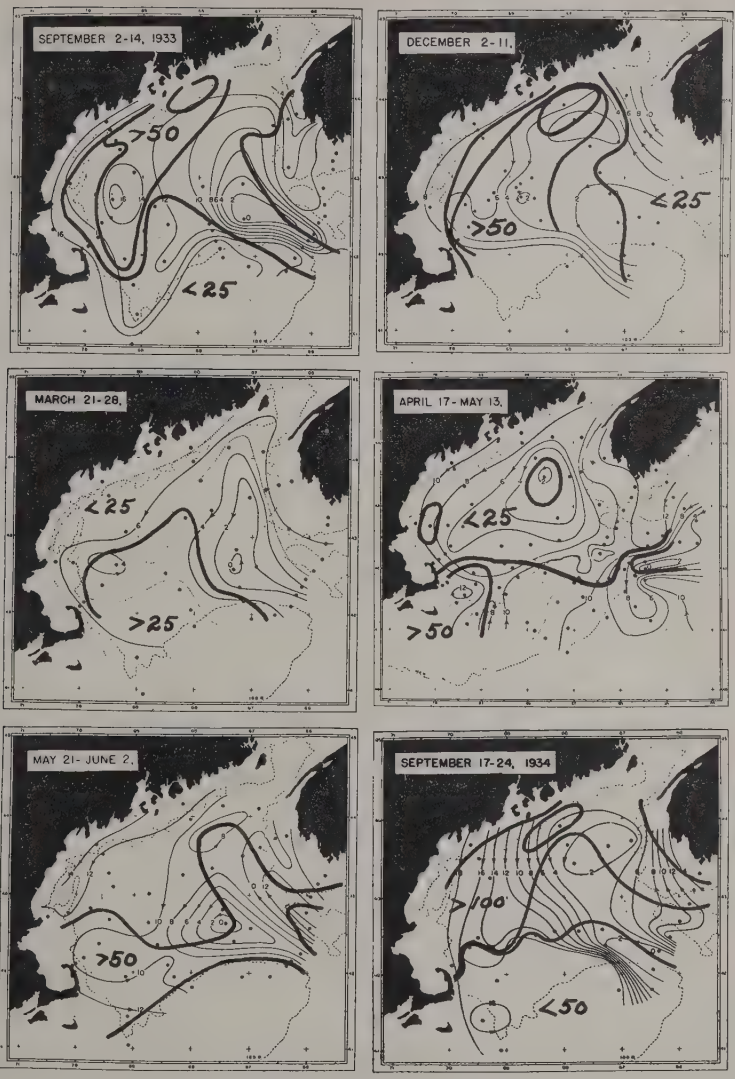

FIG. 6. Dynamic contour charts showing the theoretical circulation of the Gulf of Maine at the surface between September, 1933 and September, 1934. The heavy contours, taken from Figs. 1 and 2, indicate the relative density of population at the time of each cruise.

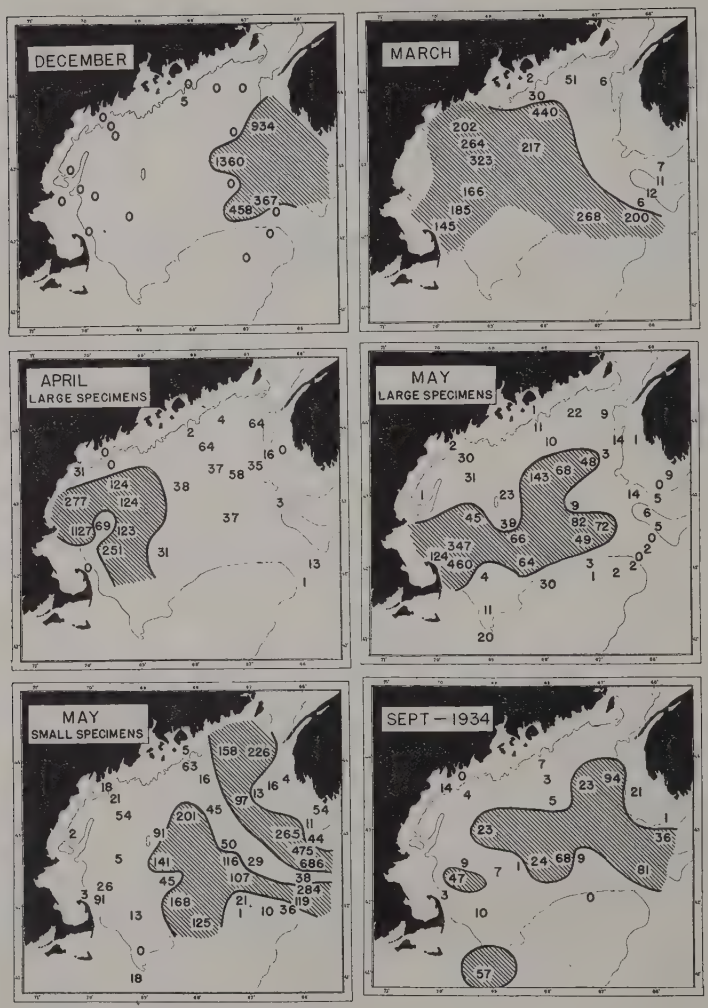

FIG. 7. The distribution of *Limacina retroversa* in the Gulf of Maine between December, 1933 and September, 1934. The numerals indicate the position and the numbers caught per haul. Compare Fig. 6 for corresponding current diagrams and the coincident distribution of the calanoid community.

mitted me to use some of his current diagrams in advance of the publication of his full report. This study has not only confirmed the more general conclusions of Bigelow, but gives the best available evidence of the actual character of the circulation at the time of our collections.

The zoöplankton population is not distributed uniformly in waters of various depth but tends on the whole to congregate in the upper 100 meters (Bigelow, 1926, p. 93). In many species, particularly of the numerically important copepods, there is a pronounced diurnal vertical migration which has been studied in the Gulf of Maine by Clarke (1933, 1934). At a station in the deep part of the Gulf, he found that *Calanus* and *Metridia* migrated to a depth of 120 meters or more during the daytime and moved upward to levels of from 6 to 42 meters at night. On Georges Bank *Calanus* was confined to the surface strata, undergoing very limited migration, but *Metridia* carried out an extensive vertical migration. Consequently the population cannot be identified exclusively with any particular layer and any attempt to correlate its distribution with the drift of the water is complicated by the undoubted migration of the animals to and from layers of different depth moving with different velocities and in some places without doubt in different directions. As a first approximation, however, it is reasonable to assume that considerable volumes of the more superficial water, unconfined in its movements by shoals, will retain for appreciable periods a unity sufficient to permit a definite population to be identified with it. The horizontal movement of the water at a depth of 40 meters should be fairly representative of the layers in which the zoöplankton chiefly occur within the Gulf. At this depth the water is unobstructed in its movements by any considerabe shoals. We have reproduced the dynamic contours at a depth of 40 meters in a recent paper (Redfield and Beale, 1940, Fig. 10). The surface circulation does not differ in important detail from the charts representing conditions at 40 meters. It shows a somewhat closer correlation with certain features of the plankton distribution. Charts showing the gradient currents at the surface have consequently been employed in preparing Fig. 6.

Additional evidence of the character of the circulation, and particularly of its influence in actually transporting a pelagic population, is provided by the distribution of *Limacina retroversa* in the Gulf during the period of this survey (Redfield, 1939). These organisms appeared en masse in the Browns sector in December and their drift was followed as they spread across the Gulf. In four months they had arrived in numbers in the western basin, having spread along the northern margin of the Gulf in the course taken by the receding center of the zoöplankton population (Fig. 7).

The Relation of Population Distribution to the Hydrography of the Gulf

The following theory is proposed to account for the seasonal fluctuation of the population of zoöplankton. The superficial current, or nontidal drift, consists of a great cyclonic eddy. The eddy is augmented by the inflow of water on the eastern side from over the Nova Scotian Banks. The inflow is compensated for by the escape of water to the south and east across the end of Georges Bank. The relative volumes of inflow and outflow vary from season to season and year to year. In the winter and early spring the inflow is sufficiently great to replace a considerable part of the eddy with water new to the Gulf. This "new" water is relatively barren and does not develop a more considerable population until conditions become favorable for growth and reproduction in the spring, by which time it has extended over the entire northern half of the eddy. Meanwhile an equal part of the older water, which had been in the Gulf during the preceding summer, escapes from the Gulf. The remainder occupies the southern half of the eddy. This water supports a rich population grown up during the previous summer and only moderately diminished by the conditions of the winter. In spring and summer the inflow and outflow diminish and the southern half of the eddy carries an increasing quantity of water northeasterly toward the Bay of Fundy, with the result that this water enters a second circuit of the Gulf, carrying with it a large population which enriches the northern half of the eddy during the late summer and fall. This region may also be enriched by an inflow of water from the Nova Scotia banks which carries a considerable population at some seasons.

The adequacy of this theory is demonstrated in Fig. 6, in which contours representing the areas of relative abundance recorded in Figs. 1 and 2 are transposed upon diagrams of the dynamic gradients in the surface waters. The general distribution of these contours was established without reference to the current diagrams.

In September, 1933, the center of population lay in relatively quiescent water along the northern margin of the Gulf and extended southwestward to occupy a secondary eddy over the western basin. A more scanty population occupied the Cultivator sector. Over the Nova Scotian Banks a condition of slack water existed with no evidence of indraft except along the eastern margin of the Eastern Channel. This water was scantily populated. A marked eddy occupies the Eastern Channel with its offshore component lying on the western side. This includes a tongue of richly populated water in which much plankton is being carried out of the Gulf. During this period the population is being impoverished by this outdraft.

By December a strong indraft of water over the Nova Scotian Banks has commenced carrying into the Gulf water containing a scanty population. This water contains abundant *Limacina* which occupy the eastern area in which catches of less than 25 cc. of plankton occurred. (Figure 7.) Compensatory movements must be expelling richly populated waters over Georges Bank.

By March scantily populated water has extended along the entire northern margin of the Gulf, carrying with it the population of *Limacina*. Considerable volumes of zoöplankton were then taken only in the southwestern quarter where relatively slack water is found. A small eddy occupies the western basin and in it *Limacina* mingle with considerable remnants of the copepod population. In the eastern half of the Gulf the major eddy is well marked. Along its eastern side water still enters the Gulf scantily populated with copepods and now containing very few *Limacina*. Its western arm is carrying many *Limacina* out to sea.

In April the character of the circulation changes abruptly from a loop to a closed eddy. Invasion of water from offshore has come practically to an end and considerable numbers of copepods which occur at the mouth of the eastern channel have no opportunity of entering the Gulf. In the west a small concentration of copepods persists near the South Channel. The *Limacina* population is now centered over the western basin, but considerable numbers appear to have spread eastward along the southern and eastern arcs of the great eddy.

Up to this time the movements of water and of the populations of copepods and *Limacina* appear to be perfectly correlated. There can be no doubt that the inflow of barren water from the east has displaced a large part of the copepod population from the northern and eastern part of the Gulf, forcing it out to sea over the eastern end of Georges Bank.

In May and June the loop-like character of the circulation reëstablishes itself, but a considerable eddy persists in the center of the loop. Reproduction now increases the population everywhere. The copepod population occurs in greatest numbers in the slack water of the western basin. From there a rich band extends along an east-flowing current out to sea over the Eastern Channel. A part of this eastward extension has evidently been caught in the recurrent eddy and carried northward toward Mount Desert. Richly populated water found in the North Channel appears to be moving out of the Gulf. The only water entering the Gulf at this time lies along the east side of the Eastern Channel and appears to be scantily populated. It seems improbable that a considerable population is being recruited at this time. The increasing numbers

observed in the eastern region apparently come from the southern and western region.

The distribution of *Limacina* in May–June agrees with this interpretation of the water movements. The population of large specimens, which had wintered in the Gulf, extends eastward along the southern side of the Gulf, and northward along the eastern side of the eddy. The small specimens, new to the Gulf, lie along the inflow and about the center of the eddy. Others follow the eastern arm of the inflow which recurves along the Nova Scotia shore.

By September, 1934 conditions have reëstablished themselves much as they were a year before. The southern half of the Gulf appears to be occupied by the more scanty population, presumably derived from the barren water which lay to the north in the spring. This is trapped in a dead water. A large population has grown up in the eddy which forms each summer in the northeast quarter and well-marked currents exist to carry this population to the southeast. The current flow into the Gulf is stronger than the year before and appears to bear an abundant population from offshore into the eastern side of the Gulf. This is the only indication that the copepod population is enriched by exchanges with offshore waters in the course of the year.

The small numbers of *Limacina* which occupied the Gulf in September, 1934 occurred in greatest numbers along the course of the inflowing water.

It is unfortunate that a more complete survey was not made between June and September. The events which are least clear are those leading to the development of the exceptional populations in the Mount Desert region in late summer. It is not certain that these may not have been recruited from offshore during the summer. The circulation calculated for May–June would appear to transport the richer water then found in the south out to sea more effectively than toward the northeast. Possibly the rich population extending northward toward Mount Desert arrived there before the loop-like eddy reestablished itself. There are, however, several considerations which support the view that the population of the northeastern sectors is recruited from the southern part of the Gulf in early summer.

Fish (1936) records the invasion of the coastal waters of Maine by *Calanus finmarchicus* larvae in June which he assigns to a "western stock." These he believes to be absent from the eastern half of the outer Gulf earlier in the season, and to have drifted in toward the Maine coast from the southwest. The larvae of this stock greatly outnumber those of an "eastern stock" which entered the Gulf from the Scotian Banks in April.

Drift-bottle observations indicate an actual movement of water from the southern toward the northeastern quarter of the Gulf in summer (Bigelow, 1927). There can be no doubt that the surface water does move in this direction, dynamic calculations notwithstanding.

It is possible that lateral mixing along surfaces of equal density may permit rather extensive exchanges of water across gradient currents (Iselin, 1939). In particular, according to a principle developed by Parr (1936), stratification in turbulent waters leads to increased lateral mixing. Thermal stratification in the Gulf of Maine was well developed in May, 1934, and its onset may have facilitated the transfer of well-populated waters across the eddy. It is noteworthy that during May a considerable intermingling of *Limacina* with water rich in copepods occurred along the southern side of the Gulf. It is also noteworthy that the distribution of *Limacina* became much more homogeneous in May than it had been earlier. This was true also of the plankton population as a whole, as Fig. 4 shows. Lateral mixing deserves more study by biologists, as Iselin has pointed out, for it may well be an important factor in preventing local breeding stocks from being swept out of embayments by directional currents.

In summary, the hydrographical evidence appears to support the view that the scanty population of the eastern sectors in midwinter is due to their occupancy by the barren water, which appears in the Browns Bank sector in December and can be traced until it enters the Massachusetts sector by May. The eastern and northern sectors thus receive an influx of relatively barren water in midwinter when the climate is unfavorable for further growth of the population. In the early summer, on the other hand, water drifts from the southern part of the Gulf into the northeastern sectors. This water is about to commence its second circuit of the Gulf and carries with it a population which has already grown to some magnitude in the sectors from Massachusetts to Georges Bank by the end of May.

In contrast to this, the sectors of the western basin receive in winter water which had acquired an abundant population in the Mount Desert and Seguin sectors during the fall. Although there is some destruction of the organisms at this season, it is not sufficient to reduce the numbers greatly. With the coming of spring, this water moves on to be replaced by the barren water found in the northern sectors during the winter. But as this water warms, its population grows and rapidly comes to equal that of the water it replaces. The uniformity of the population in the western basin is due to the fact that a rich fauna arrives there coincident with unfavorable conditions in winter, and a scanty fauna comes to occupy the region during the period most favorable for growth.

The Average Monthly Catch

The monthly catch obtained by averaging the mean values for all sectors during each cruise is given in Fig. 8. The average monthly catch remained constant at about 40 cc. per square meter from June to December, 1933. The values fall markedly from January through April. This is undoubtedly due to the destruction of the population by winter cold. At this period, however, large quantities of water poor in population are entering the Gulf and an equivalent quantity bearing a richer population is leaving, thus accounting for much of the loss.

Fig. 8. Average catch for entire Gulf during the period of survey. Ordinate: cubic centimeters of zoöplankton per square meter of sea surface. The black bars indicate the actual period occupied by each cruise.

In May the average population begins to increase suddenly and its growth continues at a diminishing rate until the last observations in September, 1934. The population as a whole is then twice as great as that encountered during the preceding year,—the average haul being 90 cc. per square meter.[2]

[2] Bigelow found that the zoöplankton was at its lowest ebb in late February and the first half of March in 1920. At this time his catches varied from 75 to 25 cc. per square meter measured wet (equivalent to 15 to 5 cc. measured "dry"). Our catches in March averaged 13 cc. and for April 8 cc. per square meter measured "dry." The 1934 year appeared to be a late year and was initiated by an unusually cold winter. The April observations are perhaps misleading since collections were not made in the parts of the Georges and Cultivator sectors where the highest population was expected. Bigelow considered 100 cc. wet (20 cc. or more measured dry) to be representative of the Gulf in midsummer, a value much smaller than our average of 40 cc. in 1933 and 80 cc. in 1934. His largest catch of 425 cc. (85 cc. "dry"), made in September, 1915, does not exceed the average value obtained in September, 1934 for all sectors. It must be remembered that he employed a different method of measuring his catch and nets which doubtless differed from ours in efficiency.

The Total Annual Production and Exchange

The average catch throughout the period of the survey in each sector, —obtained by averaging the mean figures obtained at the time of each cruise—is given in Fig. 9.[3] It is noteworthy that the catch increases progressively as one passes along the course of the water movement from its inflow over the Browns Bank sector to its exit across the end of Georges Bank. The longer the water has been in the Gulf, the greater its population.

The average catch is greatest in the Mount Desert sector and is an exception to the foregoing tendency. We suggest that this is due to the movement of water, which has already completed the circuit of the Gulf and is rich in plankton, from the southern sectors into the Mount Desert sector during the summer. The Mount Desert sector thus virtually occupies a position at the end of the series during the months when its population is greatest.

The average haul for all sectors of the Gulf and at all cruises is about 40 cc. per square meter of "dry" plankton. If the area of the Gulf be taken at 36,000 square miles, this would indicate a total population of about 3.7×10^{12} cc. or some four million tons.[4]

The standing crop does not give a measure of the rate of production of the population, since it reflects merely a balance between rate of growth and death and the gains and losses in the population by movement into or out of the region. It is clear from Fig. 8 that the crop increased by nearly 80 cc. per square meter of surface between May and September. This represents a net gain of some eight million tons.

The observations make it apparent that the Gulf loses at least one half of its population through the escape of water over Georges Bank and the Eastern Channel each winter. There is no evidence that water enters the Gulf at any time carrying a richer population than that obtaining there at the time, and only in September, 1934 was water found to enter the Gulf in which the copepod population was not distinctly

[3] This method of averaging avoids overweighting the yield of these sectors in which an unusual number of rich hauls were made at a time when the population was particularly large, as would be the case if all catches were simply averaged.

[4] In discussing the productivity of the Gulf of Maine, Bigelow concluded that the population was greatest over a band extending from the Massachusetts coast to Penobscot Bay and the Bay of Fundy. The areas occupied approximately by our Seguin sector and the greater part of the Cultivator and Georges Bank sectors were considered barren. His conclusion that the southern sectors are barren certainly rests on insufficient evidence, since only two hauls are recorded. Our richest haul was obtained over the southeastern deep in June, 1934 and the Cultivator and Georges sectors are the most populous sectors excepting Mount Desert throughout the year as indicated. Our observations agree that the Seguin sector is relatively unproductive. Its best season was the fall of the year, a time when Bigelow made relatively few cruises. Several of our richest hauls were made off Seguin in September, 1934.

scanty. Unless further observations during the summer should prove the contrary, it may be concluded that the Gulf is a region of production for the calanoid community which supplies immigrants to the southern banks in quantity, but receives relatively unimportant recruitments from the regions to the eastward.

The Growth of the Population in the Moving Mass of Water

If the interpretation which we put on the data is correct, it is certain that observations made at a geographically fixed point, or standard station, tell little about the fluctuations of any unit of the population. We record simply a series of events distributed in space as they drift past in the course of time. The conditions we observe today are not determined by the events we observed yesterday. The curves of population growth presented in Fig. 5 are grossly misleading if they are interpreted to represent the history of any biologically continuous unit.

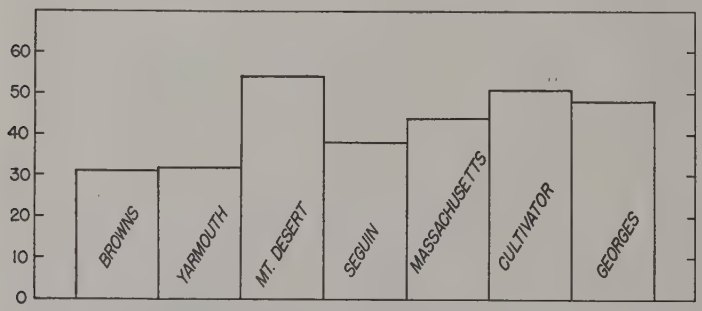

Fig. 9. The average catch in each sector during the period June, 1933 to September, 1934. Ordinate: cubic centimeters of zoöplankton per square meter sea surface.

By taking account of the rate of drift of the water, it is possible to select appropriate stations to show the growth of population in a unit volume of water as it is carried about the Gulf of Maine eddy at the apparent rate of its non-tidal drift. While the result is both an abstraction and an approximation, it probably indicates the true history of events better than the usual curves of population fluctuation. Figure 10 represents the apparent growth of the population of a unit mass of water entering the Gulf in December and recognized by the presence of *Limacina*. As the season advances it is carried across the northern sectors, arriving by May in the offing of Cape Ann. During this period the population decreases by about one-third, but in May as it crosses the western basin rapid growth occurs with the result that in midsummer

it has reached the value of 50 cc. per square meter, greater than the yearly average for the Gulf as a whole. The unit may now drift out of the Gulf across the end of Georges Bank in late summer or it may drift northeasterly into the Yarmouth sector to commence a second circuit of the Gulf. Its numbers grow meanwhile to over 100 cc. per square meter. After January 1, high mortality again reduces the numbers to about one-third or to 30 cc. per square meter, as it crosses the Massachusetts sector in March. In May growth recommences and by

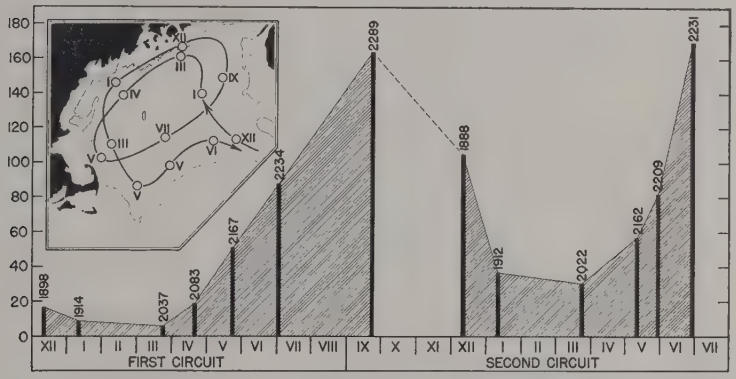

FIG. 10. The growth of population in a mass of water assumed to move along course indicated in inset. Ordinate: volume of zoöplankton in cubic centimeters per square meter sea surface; abscissa, time in months. The black bars indicate the volumes caught at the selected stations. The positions of these stations and the month of collection are indicated on the inserted chart.

midsummer it reaches the Georges sector, having attained the record volume of 170 cc. per square meter. Its history may be terminated by supposing it to be carried out of the Gulf at this time.

Figure 10 is presented because it illustrates the possibility of taking account of the current system in an ecological analysis. It may be pointed out that the life history of any individual species might be treated in a similar way.

ANNUAL FLUCTUATIONS IN POPULATION

The average catch at all stations was more than twice as great during the summer of 1934 as during the same period in 1933. Since the hauls were numerous, widely spaced, and all made with the same technique, there can be little doubt of the significance of this observation. The difference is the more striking in that an unusually severe winter preceded the richer year.

The suggested theory offers a tentative explanation of such fluctuations. The poverty of the water in the northern half of the Gulf in winter seems due to the introduction of a large volume of relatively barren water from the Scotian Banks. It is suggested that more of this water enters in some years than in others, and that the population of the Gulf is impoverished in proportion to the magnitude of this inflow. The longer water remains in the Gulf, before being replaced by new water, the richer its population becomes.

A number of facts support this suggestion. It is well known that the magnitude of the inflow varies from year to year. The inflow during the winter of 1934 seems to have been of shorter duration than usual, having been completely terminated by a strong movement of water from the Gulf over the North Channel and adjoining banks in May. The movement was apparently underway in the latter part of April, as the current diagrams show (Fig. 6). Drift bottles set out by Dr. Herrington off Cape Sable at that time were recovered to the eastward. In contrast to this, Bigelow observed the invasion of the Gulf by Nova Scotian water to continue until May or June and to result in a cooling of the eastern part of the Gulf long after the other parts had commenced to warm. He speaks of the invasion as a phenomenon of spring, whereas in 1934 it terminated before the end of winter.

It is also possible that differences in the circulation such as those observed in September, 1933 and 1934 may cause the population of the Gulf to be augmented from external sources to a different degree each season.

Since the water flowing into the Gulf over the Nova Scotian Banks is less saline than that occurring at like depth within the basins, a small influx of this water should be followed by a summer of relatively high salinity. The superficial water of the Gulf was exceptionally salt in 1934. It appears to have been as salt or salter than in 1915, the most saline year recorded by Bigelow. In 1933, on the other hand, the water was quite as fresh as in 1914 and 1916, the least saline of those he recorded. A correlation between salinity, productivity, and annual inflow over the Scotian Banks is strongly suggested. Systematic annual observations would serve to test this relation, and should it prove general, might lead to an understanding of the yearly fluctuations in commercial fisheries.

The Distribution of Petrels and Mackerel

The zoöplankton supplies food for various predators. Their distribution may be expected to be influenced secondarily by the hydrographic factors which determine the abundance of the calanoid community.

Petrels

These birds appear to feed upon zoöplankton or their products. They pick up whatever scraps of organic matter they can find, gathering about fishing vessels, following ships, and feeding about the carcasses of dead whales and seals. There is a general belief that they pick up droplets of oil from the surface of the water, and their stomachs frequently contain an oily fluid which they eject when captured. It seems

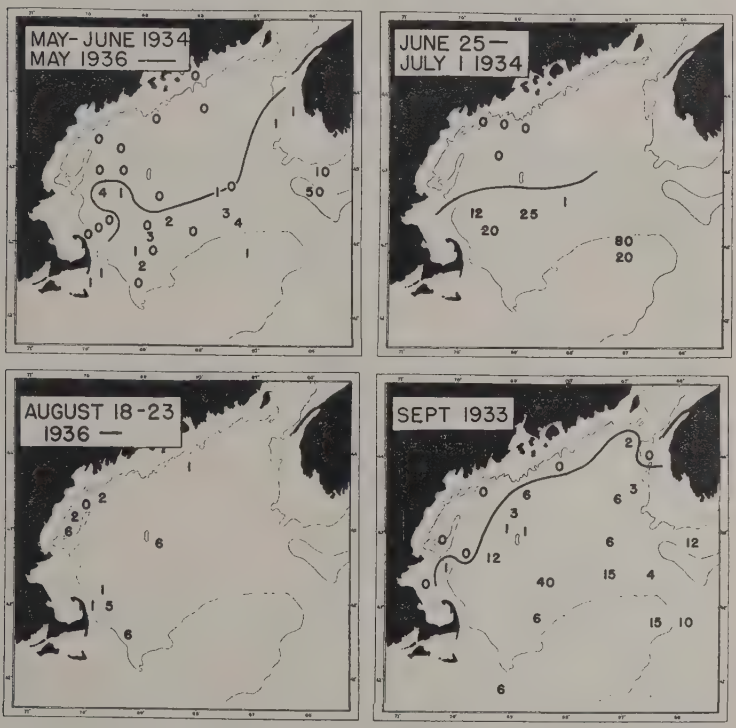

FIG. 11. Numbers of petrels observed in different parts of the Gulf of Maine during cruises at various times of year.

more probable that this is derived directly from their food. Wilson (1907) states that the food of the Wilson's petrel, which he observed in the antarctic, consists of minute crustaceans. The natural food of the Leach's petrel, according to Bent (1922, p. 143) "includes shrimps and other small crustaceans, floating mollusks, perhaps small fishes occa-

sionally, and probably many other forms of minute marine animals which are found swimming on the surface or in floating masses of seaweed."

Wilson's petrel is the common petrel of the Gulf of Maine. Leach's petrel, though a breeder along the coast of Maine, is much scarcer. Not more than one petrel in twenty or thirty observed at sea is of this species. Wilson's petrel breeds in the south Atlantic during December, January and February and does not reach the Gulf of Maine until May. None were observed during the cruise of April 19–23, 1934. In cruises in May, 1934 and 1936 petrels were observed in small numbers in the southern and eastern regions, where at that season the largest zoöplankton hauls were taken, but were absent from the northern sectors which at the time were occupied by relatively barren water (Fig. 11). During

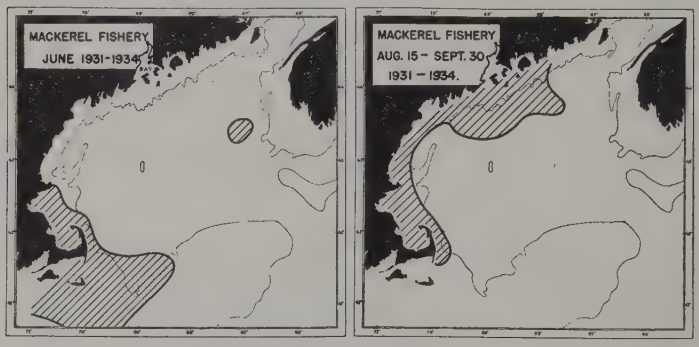

FIG. 12. The areas occupied by the mackerel fishery during the early and late summer 1931–1934.

a cruise from June 25 to July 1, 1934, petrels were present in larger numbers in the southwestern quarter, but were not observed in the Seguin sector. On August 18 to 23, 1936, however, petrels were observed regularly at stations made in the northern side of the Gulf. In September, 1933 petrels were observed everywhere in the Gulf except at a few coastwise stations along the shore. At this time all sectors supported an abundant population of zoöplankton.

It appears that when Wilson's petrel first arrives in early summer it remains confined to those sectors of the Gulf which then support the richest plankton.

Mackerel

In the Gulf of Maine these fish have long been known to feed on calanoid copepods and are known to eat various other crustaceans which

compose the bulk of the zoöplankton (Bigelow, 1926, p. 102). It is not surprising in consequence to find a correlation between the seasonal distribution of this fishery and of the local abundance of zoöplankton.

Dr. Settee has kindly placed at my disposal the very complete records made by the U. S. Bureau of Fisheries showing the places in which mackerel have been taken during recent years. The mackerel fishery begins in New England waters with the arrival of the fish south of Cape Cod in May and June. The fish are first taken along the shores of the Gulf of Maine in June, chiefly within the 100-meter contour from Cape Ann to Cultivator shoal. At this time heavy catches are also made along the east coast of Nova Scotia and northward to Gaspé (Settee and Needler, 1934). The July fishery has much the same distribution, though tending to spread farther east along Georges Bank and also in some years along the western part of the coast of Maine. In August and September a considerable fishery is conducted in the northern side of the Gulf, from Mount Desert westward, and southward as far as Cape Cod (Fig. 12). During these months the fishery in the Bay of Fundy is at its height, 37 per cent of the total catch being made during each of these two months, whereas less than 10 per cent is taken in any one of the preceding or following months.

In interpreting these facts the peculiarities of the fishermen as well as of the fish must be borne in mind. Mackerel are now marketed fresh and are landed chiefly in Boston. The fishermen consequently do not fare farther from this port than is necessary. The takings of mackerel do not reflect accurately the total distribution of the fish, but only their availability to the Boston market. It seems sufficiently clear that in early summer mackerel are available chiefly along the southern shores of the Gulf; that by late summer their abundance has shifted to the northern shores, including the Bay of Fundy. This is the distribution of the maximum of zoöplankton population as well. Whether the mackerel follow the plankton as it drifts around the great eddy, or cut across to meet its advance from the east in the late summer, as the fishermen undoubtedly do, cannot be told.

Thus there appears to be a general correlation between the distribution of the zoöplankton, the occurrence of petrels, and the capture of mackerel.

Summary

1. The seasonal and geographical fluctuations of the abundance of the calanoid community of the Gulf of Maine are described.

2. The shift in the center of abundance is closely correlated with the superficial circulation, deduced from hydrographic observations and the drift of an invading population of *Limacina*.

3. The principal factor influencing the distribution of population density is the inflow of relatively barren water from the Nova Scotian coast in winter.

4. The Gulf appears to be an area from which the calanoid community spreads to other waters, but which receives relatively small recruitments from without its borders.

5. A breeding stock is maintained by the establishment of a recurrent eddy in the late spring.

6. Estimates of annual productivity and seasonal mortality are given.

7. The distribution of petrels and of the mackerel fishery appears to be correlated with the distribution of zoöplankton.

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SOME FORAMINIFERA OF THE FAMILY TEXTULARIIDAE COLLECTED BY THE FIRST "ATLANTIS" EXPEDITION

BY C. G. LALICKER AND P. J. BERMUDEZ

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SOME FORAMINIFERA OF THE FAMILY TEXTULARIIDAE COLLECTED BY THE FIRST "ATLANTIS" EXPEDITION(*)

By C. G. Lalicker and P. J. Bermúdez

The species described in this paper are mainly from bottom samples collected during the first expedition of the *Atlantis*, of the Woods Hole Oceanographic Institution, to Cuba during the spring of 1938. The expedition was sponsored jointly by Harvard University and the Universidad de la Habana. Some of the species are from bottom samples which were collected by P. J. Bermúdez in the shallow waters along the north coast of Cuba.

Previous to this expedition the dredging for deep sea biological specimens in Cuban waters had been done off Havana as the exploring ships entered or left the harbor. The first *Atlantis* expedition made a circuit of the island of Cuba and obtained material from 76 stations at depths ranging from 200 to 2125 fathoms. These dredgings yielded a wealth of intesting material from all types of marine life. The new species of foraminifera will be gradually described as the Textulariidae are in the present work.

In order to add to the knowledge of the fauna between shallow water and a depth of 200 fathoms, the *Atlantis* made a second circuit of the island of Cuba during the spring of 1939. This material is now being examined and when completed there will be much more definite information concerning the distribution of species and families in the different life zones, their relative abundance, and ecologic relationships.

It is a pleasure to be able to acknowledge again the work of Dr. Thomas Barbour, Director of the Museum of Comparative Zoology at Harvard University, Dr. Henry W. Bigelow, Director of the

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Woods Hole Oceanographic Institution, and the late Ing. José M. Cadenas, former Rector of the Universidad de la Habana, who made the expeditions possible. And we especially acknowledge the work of Drs. William C. Schroeder and Luis Howell Rivero, who supervised the dredging on board the *Atlantis*. We are very grateful to Dr. Joseph A. Cushman, Director of the Cushman Laboratory for Foraminiferal Research, Sharon, Mass., for supervising the drawing of the specimens and for many helpful suggestions. We are indebted to Ann Shepard for her painstaking work on the drawings.

In the study of the material from these collections, some interesting results have been obtained. Several species have been found in this area which were previously known only from the Pacific and Indian Oceans. *Textularia lythostrota* (Schwager), which is present in Pliocene sediments of Kar Nicobar and New Guinea, and which is rather common in the tropical Pacific, has been noted in the Caribbean Sea for tre first time. *T. schencki* Cushman and Valentine, which is common in the eastern Pacific, has also been found in the Caribbean Sea for the first time. *T. schencki* Cushman and Valentine, land, a common species in the Indian and Pacific Oceans, has been extended to the waters adjacent to Cuba. All of the species of Textulariidae which were described and figured by d'Orbigny in his report on the foraminifera of the shore sands of Cuba in 1839, have been found in these collections.

The holotypes of the new species described in this report and the figured specimens are deposited in the collections of the Museum of Comparative Zoology of Harvard University. Paratypes of the new species and a representative collection have been deposited in the Cushman Laboratory for Foraminiferal Research, Sharon, Massachusetts, and in the Museo Poey, Universidad de la Habana, Habana, Cuba.

Bigenerina lytta Lalicker and Bermúdez, new species

(PLATE 1, FIGURES 1 a-c)

Test elongate, slender, compressed, the biserial and uniserial portions about equal in length, peripheral margins rounded; sutures distinct, depressed, slightly oblique; wall finely arenaceous, smoothly finished, composed of fine arenaceous and calcareous grains with a few large grains, cemented with calcareous cement; aperture in the biserial stage as in *Textularia*, in the uniserial stage it is round and terminal. Length of holotype, 0.96 mm.; width, 0.26 mm.; thickness, 0.16 mm.

Holotype.—M. C. Z. no. 1; from *Atlantis* station 3000, latitude 23° 10′ N., longitude 81° 29′ W., 160 fathoms.

Bigenerina lytta was also present at *Atlantis* station 2980 (A complete list of stations giving the location and the depth may be found at the end of the systematic descriptions).

Bigenerina nodosaria d'Orbigny, var. textularioidea (Goës)

(Plate 1, figures 2 a, b)

Textularia sagittula Defrance, forma *bigenerina* Goës, K. Svensk. Vet. Akad. Handl., vol. 19, pt. 4, 1882, p. 78, pl. 5, figs. 159, 160.

Clavulina textularioidea Goës, l. c., vol. 25, 1894, p. 42, pl. 8, figs. 387-399.

Bigenerina nodosaria Flint, U. S. Nat. Mus. Rept. for 1897 (1899), p. 286, pl. 31, fig. 4; Cushman, U. S. Nat. Mus. Proc., vol. 59, 1921, p. 51; Carnegie Inst. Washington Publ. 311, 1922, p. 25, pl. 2, figs. 5, 6.

Bigenerina nodosaria d'Orbigny var. *textularioidea* Cushman, U. S. Nat. Mus. Bull. 104, pt. 3, 1-22, p. 25, pl. 5, figs. 8, 9; Florida Geol. Survey Bull. 4, 1930, p. 18, pl. 1, fig. 10; Cushman and Ponton, Florida Geol. Survey Bull. 9, 1932, p. 42, pl. 1, fig. 8; Cushman and Cahill, U. S. Geol. Surv. Prof. Paper 175A, 1933, p. 8, pl. 1, fig. 14.

Test very long, broad, tapering, the early biserial portion consisting of several pairs of alternating chambers followed in the adult by several uniserially arranged subglobular chambers, the last-formed chambers of the test often being greater in size than the entire biserial portion, uniserially arranged periphery broadly rounded; sutures distinct, depressed, straight in the biserial portion, and strongly oblique; wall coarsely arenaceous with considerable cement, roughly finished; aperture in the early biserial portion as in *Textularia*, in the adult uniserial portion terminal, usually with a short neck. Length, up to 6 mm.

Bigenerina nodosaria d'Orbigny, var. *textularioidea* (Goës) has been recorded from the Miocene sediments of Florida. It has been found at a number of stations in the Caribbean. It was present in the collections from the following *Atlantis* stations from the northeast coast of Cuba: 2953, 2963, 2971, 2980, 2995 and 3000.

Bigenerina perna Lalicker and Bermúdez, new species

(Plate 1, figures 3, 4)

Test elongate, rounded, increasing rapidly in size from a small pointed initial end, peripheral margins broadly rounded, subovate in top view; chambers in the early portion low and broad, in the adult portion about as wide as high, inflated, in adult forms all of the chambers except the last one are arranged biserially; sutures some-

what indistinct, depressed, slightly oblique; wall coarsely arenaceous, roughened, composed of fine and coarse siliceous and calcareous grains cemented with calcareous cement; aperture in the early stages as in *Textularia,* in the adult stage it is rounded and terminal. Length of holotype, 1.3 mm.; width, 0.60 mm.; thickness, 0.57 mm.

Holotype.—M. C. Z. no. 3; from *Atlantis* station 2982, latitude 22° 48′ N., longitude 78° 50′ W., 210 fathoms.

Bigenerina perna has also been noted at *Atlantis* stations 2980, 2983A, 2995 and 3000.

Spiroplectammina gramen (d'Orbigny)

(Plate 1, figures 5, 6)

Vulvulina gramen d'Orbigny, in De la Sagra, Hist. Fis. Pol. Nat. Cuba, "Foraminiferes", 1839, p. 148, pl. 1, figs. 30, 31; Foram. Foss. Vienne, 1846, p. 251, pl. 21, figs. 46, 47.

Textularia transversaria Flint (not H. B. Brady), Rep. U. S. Nat. Mus., 1897 (1899), p. 283, pl. 28, fig. 4.

Textularia floridana Cushman, Dept. Mar. Biol. Carnegie Inst. Washington, vol. 17, 1922, p. 24, pl. 1, fig. 7; U. S. Nat. Mus. Bull. 104, pt. 3, 1922, p. 18, pl. 2, figs. 11, 12.

Test elongate, tapering, rapidly increasing in width in the early portion, sides nearly parallel in the biserial portion; chambers in earliest portion coiled, followed by numerous biserial chambers in the megalospheric form, and in the microspheric form there is usually one chamber which tends to be uniserial above the biserial portion, chambers are wider than high and slightly inflated, terminating at the peripheral margin in a short, tubular spine, which is sometimes broken; sutures distinct, depressed, straight and somewhat oblique; wall finely arenaceous with a large proportion of cement, and smoothly finished; aperture usually as in *Textularia,* but an elongate slit which is not entirely terminal in the microspheric form. Length, up to 0.75 mm.; greatest width, 0.33 mm.

Spiroplectammina gramen has been referred to the genera *Vulvulina* and *Textularia.* Inasmuch as the common megalospheric forms exhibit all of the characteristics of *Spiroplectammina,* and since the last chamber of the microspheric form is not definitely uniserial and the aperture is not terminal, the writers believe that this species should be assigned to the genus *Spiroplectammina.* This species shows the trend of evolution of the genus *Spiroplectammina* in tend-

ing to develop the characteristics of the genus *Vulvulina* in the adult microspheric form.

Spiroplectammina gramen is very common at many stations off the coast of Florida and the West Indies. It has been recorded at a number of *Atlantis* station which are located along the north coast of Cuba, as follows: 2963, 2980, 2995, 2999 and 3000. It has also been found in Bermúdez station R28.

Textularia agglutinans d'Orbigny

(Plate 1, figures 7 a-c)

Textularia agglutinans d'Orbigny, in De la Sagra, Hist. Fis. Pol. Nat. Cuba, "Foraminiferes", 1839, p. 136, pl. 1, figs. 17, 18, 32, 34; H. B. Brady, Rep. Voy. *Challenger*, Zool., vol. 9, 1884, p. 363, pl. 43, figs. 1 a, b; Goës, Bull. Comp. Zool., vol. 29, 1896, p. 41; Flint (part), Rep. U. S. Nat. Mus., 1897, p. 284, pl. 29, fig. 4; Cushman, U. S. Nat. Mus. Bull. 71, pt. 2, 1911, p. 9, figs. 10 a, b (in text); Proc. U. S. Nat. Mus., vol. 59, 1921, p. 49, pl. 11, figs. 1-3; U. S. Nat. Mus. Bull. 100, vol. 4, 1921, p. 106, pl. 20, fig. 8; Carnegie Inst. Washington Publ. 311, 1922, p. 22, pl. 1, fig. 6; U. S. Nat. Mus. Bull. 104, pt. 3, 1922, p. 7, pl. 1, figs. 4, 5; Carnegie Inst. Washington Publ. 344, 1926, p. 76; U. S. Nat. Mus. Bull. 161, pt. 1, 1932, p. 10, pl. 2, figs. 5-7; Lacroix, Bull. Instit. Oceanogr. No. 591, 1932, p. 16, fig. 14 (in text). Lalicker and McCulloch, Allan Hancok Pacific Exped., vol. 6, no. 2, 1940, p. 117, pl. 13, figs. 2 a-c.

Test elongate, tapering, very little compressed, periphery rounded, the increase in diameter from the initial end rather uniform, sides in adult portion nearly parallel; chambers inflated, wider than high, increasing somewhat in height toward the apertural end rather uniformly; sutures distinct, depressed, usually about at right angles to the long axis of the test; wall rather coarsely arenaceous, but smoothly finished; aperture an elongate slit in a definite re-entrant at the base of the inner margin of the last chamber, with a slight upper lip. Length, 0.80-1.00 mm.; width, 0.50-0.60 mm.

Textularia agglutinans is common in the shallow waters adjacent to the West Indies. It has been reported from many localities in the tropical Pacific. It is present off the west coast of Ecuador and in the shallow waters of the Galapagos Islands. It is common in the Miocene of Florida. It has been found at a number of stations along the north coast of Cuba as follows: *Atlantis* stations: 2980 and 2999. Bermúdez stations: R1, R6, R8, R13, R22 and R28.

Textularia albatrossi Cushman

(Plate 2, figures 1 a-c)

Textularia concava Flint (not Karrer) (part), Rep. U. S. Nat. Mus., 1897 (1899), p. 283.

Textularia albatrossi Cushman, U. S. Nat. Mus.. Bull. 104, pt. 3, 1922, p. 14, pl. 2, figs. 5, 6.

Test elongate, tapering, initial end bluntly pointed, apertural end broadly angled, subquadrate, breadth and thickness nearly equal in the adult portion of the test, sides concave, periphery flattened and at right angles to the sides; chambers distinct, the last ones inflated, low and broad, each with a re-entrant portion near the central part at each side; sutures distinct, depressed, wall coarsely arenaceous, but rather smoothly finished, especially in the later portion; aperture a long, narrow slit above the base of the last chamber, with a slight lip. Length, up to 1.75 mm.

Textularia albatrossi has been recorded from the western part of the Caribbean Sea and from the shallow waters of the Atlantic Ocean northeast of Puerto Rico. It has been found at two *Atlantis* stations off the north coast of Cuba.

Textularia calva Lalicker

(Plate 2, figures 2, 3)

Textularia calva Lalicker, Smithsonian Misc. Coll., vol. 91, no. 22, 1935, p. 1, pl. 1, figs. 1, 2; Lalicker and McCulloch, Allan Hankock Pacific Exped., vol. 6, no. 2, 1940, p. 120, pl. 13, figs. 6 a-d.

Test very large, elongate, roughtly triangular in front and side views, broadly ovate in end view, initial end slightly compressed, pointed in the microspheric form, and rounded in the megalospheric form; chambers numerous, low and broad, increasing in height gradually as added; sutures indistinct except in early portion, somewhat depressed, straight, and slightly oblique; wall coarsely arenaceous, composed of sand grains and calcareous fragments, very roughly finished except on the apertural face, where it is rather smoothly finished; aperture a very low, broad opening at the base of the inner margin of the last-formed chamber; color gray. Length, up to 1.75 mm.; width, up to 1.10 mm.; thickness, up to 1.04 mm.

This species was first noted in the waters of the Caribbean Sea off the south coast of Puerto Rico. It has been found in the shallow waters off the west coast of Mexico, Costa Rica, and Colombia. It is present at the following *Atlantis* stations: 2959, 2960A, 2963, 2966,

2980, 2982, 2983, 2985, 2995 and 3000. These stations are located off the north and south coasts of Cuba in water ranging in depth from 160 fathoms to 2050 fathoms.

Textularia candeiana d'Orbigny

(Plate 2, figures 4 a-c)

Textularia candeiana d'Orbigny, in De la Sagra, Hist. Fis. Pol. Nat. Cuba, "Foraminiferes", 1839, p. 143, pl. 1, figs. 25-27; Fornasini, Mem. Accad. Sci. Istit. Bologna, ser. 5, vol. 10, 1903, pl. 0, fig. 8; Chapman, Rep. Foram. Subantarctic Islands, New Zealand, 1909, p. 329; Cushman, U. S. Nat. Mus., Bull. 71, pt. 2, 1911, p. 12, figs. 14-17 (in text); Heron-Allen and Earland, Trans. Zool. Soc. London, vol. 20, pt. 2, 1915, p. 627, pl. 47, figs. 10-16; Trans. Linn. Soc. London, vol. 11, ser. 2, 1916, p. 230, pl. 41, figs. 1, 2; Journ. Roy. Micr. Soc., 1916, p. 41; Cushman, Carnegie Inst. Washington, Publ. 291, 1922, p. 32; Proc. U. S. Nat. Mus., vol. 59, 1921, p. 50, pl. 11, figs. 7, 8; U. S. Nat. Mus., Bull. 100, vol. 4, 1921, p. 109; Carnegie Inst. Washington Publ. 311, 1922, p. 32, pl. 2, fig. 2; U. S. Nat. Mus., Bull. 104, pt. 3, 1922, p. 8, pl. 1, figs. 1-3; Heron-Allen and Earland, British Antarctic Exped., Zool., vol. 6, 1922, p. 119; Journ. Linn. Soc. Zool., vol. 35, 1924, p. 618; Hanzawa, Jap. Journ. Geol. Pal., vol. 4, 1925 (1926), p. 38 (table); Cushman, Carnegie Inst. Washington, Publ. 344, 1926, p. 76; U. S. Nat. Mus., Bull. 161, pt. 1, 1932, p. 9, pl. 2, figs. 4 a, b; Lalicker and McCulloch, Allan Hankock Pacific Exped., vol. 6, no. 2, 1940, p. 121, pl. 13, figs. 7 a-c.

Textularia sagittula Defrance, var. *candeiana* Millet, Journ. Roy. Micr. Soc., 1899, p. 562, pl. 7, fig. 2.

Test elongate, roughly triangular in front view, club-shaped in side view, ovate in top view, the early portion slender and compressed, expanding gradually to the rounded adult portion, the peripheral margin is subacute in the early portion and broadly rounded in the upper portion; chambers numerous, low, broad, and flat in the early portion, later chambers enlarge rapidly, the final ones being highly inflated; sutures distinct, slightly depressed, straight and oblique; wall rather coarsely arenaceous, being composed of fine and coarse sand grains embedded in a matrix of calcareous cement, smoothly finished; aperture a broad, low slit at the base of the inner margin of the last-formed chamber. Length, up to 1.00 mm.; maximum width, 0.65 mm.; maximum thickness, 0.50 mm.

This species is very widespread in the present oceans. It has been noted in the tropical Pacific and along the west coast of California, Mexico, Central America, Colombia, and Peru. This species, which is common in the waters adjacent to the West Indies, has been found at the following Bermúdez stations: R6, R8, and R28. All of these stations are located in the shallow waters along the north coast of Cuba.

Textularia caribaea d'Orbigny

(Plate 2, figures 5, 6)

Textularia caribaea d'Orbigny, in De la Sagra, Hist. Fis. Pol. Nat. Cuba, "Foraminiferes", 1839, p. 145, pl. 1, figs. 28, 29.

Test elongate, slender, lancet-shaped, gradually increasing in width from the sharply pointed initial end, subquadrate in top view, peripheral margin rounded; chambers numerous, low and broad, about twice as wide as high except in the last-formed chambers which are nearly equal in width and height, inflated; sutures very distinct, depressed, oblique, making an angle of about 20° with the horizontal axis; wall finely arenaceous, smooth, composed of fine arenaceous grains cemented with calcareous cement; aperture a low, wide, slightly arched opening located just above the base of the last chamber, with a distinct lip. Length of figured specimen, fig. 6, 0.97 mm.; width, 0.40 mm.; thickness, 0.27 mm.

Textularia caribaea was described by d'Orbigny from the shore sands of Cuba. In the present collections it was found in abundance at *Atlantis* station 2980, and at Bermúdez station R1, both of which are located in the shallow waters of the north coast of Cuba.

Textularia catenata Cushman

(Plate 2, figures 7 a-c)

Textularia catenata Cushman, U. S. Nat. Mus., Bull. 71, pt. 2, 1911, p. 23, figs. 39-40 (in text); U. S. Nat. Mus., Bull. 100, vol. 4, 1921, p. 112, pl. 23, fig. 5; U. S. Nat. Mus., Bull. 104, pt. 3, 1922, p. 12, pl. 6, fig. 3; Carnegie Instit. Washington, Publ. 342, 1924, p. 16, pl. 2, figs. 6, 7.

Test elongate, triangular in front view, subovate in end view; chambers low and broad in the early part of the test, inflated and globular in the upper part; sutures distinct, depressed rather deeply; wall rather coarsely arenaceous but smoothly finished; aperture in the early chambers slitlike at the ventral border of the inner margin of the chamber, in later chambers gradually growing away from the margin, and in the last-formed chamber of the adult it is subterminal and rounded with a distinct lip. Length, up to 1.00 mm.

Textularia catenata has been recorded from a few stations in the North Pacific in the vicinity of the Philippines, and from some stations in the North Atlantic southeast of New York. It is present at Atlantis stations 2960, 2963, 2980 and 2995, which are located north and south of Cuba.

Textularia concava (Karrer)

(Plate 3, figures 1 a-c)

Plecanium concava Karrer, Sitz. k. Ak. Wiss. Wien., vol. 58, Abth. 1, 1868, p. 129, pl. 1, fig. 3.

Textularia concava H. B. Brady, Rep. Voy. *Challenger*, Zool., vol. 9, 1884, p. 360, pl. 42, figs. 13, 14; pl. 43, fig. 11; Millett, Journ. Roy. Micr. Soc., 1898, p. 559, pl. 7, fig. 5; Fornasini, Mem. Accad. Sci. Instit. Bologna, ser. 5, vol. 10, 1903, p. 10, pl. 0, fig. 11; Sidebottom, Mem. Proc. Manchester Lit. Philos. Soc., vol. 49, no. 5, 1905, p. 7, pl. 1, fig. 11; Cushman, U. S. Nat. Mus., Bull. 71, pt. 2, 1911, p. 22, fig. 38 (in text); Heron-Allen and Earland, Trans. Zool. Soc. London, vol. 20, 1915, p. 624; Halkyard, Mem. Proc. Manchester Lit. Philos. Soc., vol. 62, pt. 2, 1918 (1919), p. 32; Lacroix, Bull. Instit. Oceanogr., no. 582, 1931, p. 12, figs. 7 a-c (in text); Cushman, U. S. Nat. Mus., Bull. 161, pt. 1, p. 13, pl. 3, figs. 6 a, b; Lacroix, Bull. Instit. Oceanogr., no. 591, 1932, p. 14, figs. 10-12 (in text).

Test about twice as long as broad, strongly tapering, distinctly concave in the middle of the flattened sides, and slightly concave on the peripheral margins, quadrangular; chambers numerous, about twice as wide as high, slightly inflated and overlapping the preceding chamber slightly, increasing gradually in height as added; sutures distinct, only slightly depressed, straight and strongly oblique; wall finely arenaceous with a large proportion of cement, and smoothly finished; aperture an elongate opening above the inner margin and at an angle to it, with a complete lip encircling the opening. Length, up to 0.75 mm.; greatest width, 0.45 mm.; thickness, 0.28 mm.

Textularia concava has been recorded in sediments of Eocene, Oligocene, and Miocene age in Europe. It has been found in dredgings from the Mediterranean Sea, the Caribbean Sea, and the South Pacific Ocean. It is present at *Atlantis* stations 2963, 2980 and 2995, which are located off the north coast of Cuba.

Textularia conica d'Orbigny

(Plate 3, figures 2 a-c)

Textularia conica d'Orbigny, in De la Sagra, Hist. Fis. Pol. Nat. Cuba, "Foraminiferes", 1839, p. 143, pl. 1, figs. 19, 20; H. B. Brady, Rep. Voy. *Challenger*, Zool., vol. 9, 1884, p. 365, pl. 43, figs. 13, 14; pl. 113, fig. 1; Goës, Bull. Mus. Comp. Zool., vol. 29, 1896, p. 43; Cushman, Proc. U. S. Nat. Mus., vol. 59, 1921, p. 50, pl. 11, figs. 4-6; U. S. Nat. Mus., Bull. 100, vol. 4, 1921, p. 123, pl. 25, figs. 2 a-c; Carnegie Inst. Washington Publ. 311, 1922, p. 24, pl. 2, fig. 4; U. S. Nat. Mus., Bull. 104, pt. 3, 1922, p. 22, pl. 5, figs. 5-7; Carnegie Inst. Washington Publ. 342, 1924, p. 15, pl. 1, fig. 6; U. S. Nat.

Mus., Bull. 161, 1932, p. 11, pl. 2, figs. 8-10; pl. 3, figs. 1, 3; Lalicker and McCulloch, Allan Hankock Pacific Exped., vol. 6, no. 2, 1940, p. 126, pl. 14, figs. 8 a-c.

Test small, triangular in front view, usually wider than high, broadly oval in end view, somewhat compressed, peripheral margin subacute, initial end bluntly pointed; chambers comparatively few, low and broad, gradually increasing in height as added, slightly inflated; sutures distinct, slightly depressed, nearly horizontal but tending to curve downward near the peripheral margin; wall arenaceous, smooth or slightly roughened with a large proportion of calcareous cement; aperture a narrow slit at the base of the inner margin of the last-formed chamber. Length, up to 1.00 mm.; greatest width, up to 1.00 mm.; thickness, up to 0.50 mm.

Textularia conica d'Orbigny is widely distributed in the waters adjacent to the West Indies. It has been noted at a number of localities in the tropical Pacific. It is present at a large number of localities off the west coast of Mexico, Central America and Colombia. It is very common in the shallow waters adjacent to the Galapagos Islands. *T. conica* has been found at the following Bermúdez stations: R5, R13 and R28.

Textularia corrugata Heron-Allen and Earland

(Plate 3, figures 3 a-c)

Textularia conica d'Orbigny, var. *corrugata* Heron-Allen and Earland, Trans. Zool. Soc. London, vol. 20, 1915, p. 629, pl. 47, figs. 24-27.

Textularia corrugata Cushman (not Costa), U. S. Nat. Mus., Bull. 161, pt. 1, 1932, p. 12, pl. 3, figs. 2, 4; Lalicker and McCulloch, Allan Hankock Pacific Exped., vol. 6, no. 2, 1940, p. 126, pl. 14, figs. 9 a-d.

Test short and broad, triangular in front view, compressed, subovate in end view, peripheral margin sub-acute, thickest in central portion; chambers numerous, highly inflated at upper margin, depressed at lower margin, much broader than high; sutures very distinct, depressed, curving upward in the middle portion and downward near the peripheral margin; wall distinctly arenaceous, composer of fine sand grains with considerable cement, giving it a smooth finish; aperture a low, broad opening at the base of the inner margin of the last-formed chamber, in a distinct re-entrant. Length and breadth, up to 1.00 mm.

This species has been reported from the Kerimba Archipelago and from numerous localities in the tropical Pacific. It is present at a large number of localities off the west coast of Mexico and Central America. It has been found at the following Bermúdez sta-

tions along the north coast of Cuba: R5, R8, R13, R20 and R28. It was found at *Atlantis* station 2966, south of Cuba.

Textularia flintii Cushman

(Plate 3, figures 4 a-c)

Textularia agglutinans Flint (not d'Orbigny), Rep. U. S. Nat. Mus., 1897 (1899), p. 284, pl. 29, fig. 4 (part).

Textularia rugosa Bagg (not Rouss), Proc. U. S. Nat. Mus., vol. 34, 1908, p. 131.

Textularia flintii Cushman, U. S. Nat. Mus., Bull. 71, pt. 2, 1911, p. 21, figs. 36 a, b (in text); l. c., Bull. 100, vol. 4, 1921, p. 113, pl. 22, fig. 4; Bernice P. Bishop Museum, Bull. No. 27, 1926 (1926), p. 124; Yabe and Hanzawa, Jap. Journ. Geol. Pal., vol. 4, 1925 (1926), p. 50.

Test triangular in front view, irregularly rhombic in end view, rapidly increasing in size from the early portion, rather thick, but somewhat compressed laterally; chambers numerous, low and broad, inflated, separated by rather deep sutures; wall very finely arenaceous with large proportion of calcareous cement, smooth and shining; aperture an elongated slit slightly above the inner base of the last chamber, often with a slightly raised lip. Length about 1 mm.

Textularia flintii has been recorded from a large number of stations in the Pacific Ocean and from one station east of Puerto Rico. It was noted only at *Atlantis* station 2959, which is south of Cuba.

Textularia flintii Cushman, var. curta Cushman

(Plate 3, figures 5 a-c)

Textularia agglutinans Flint (not d'Orbigny) (part), Rep. U. S. Nat. Mus., 1897 (1899), p. 284, pl. 29, fig. 4.

Textularia rugosa Bagg (not Rouss), Proc. U. S. Nat. Mus., vol. 34, 1908, p. 131.

Textularia flintii Cushman, var. *curta* Cushman, U. S. Nat. Mus., Bull. 104, pt. 2, 1911, p. 21, figs. 36 a, b (in text).

The variety differs from the typical form in having a more rounded periphery and in being a broader, shorter form.

Textularia flintii, var *curta* has been recorded from several stations in the Caribbean Sea. In the present collections it has been noted only at *Atlantis* station 2963, which is located just south of Cuba.

Textularia lythostrota (Schwager)

(Plate 3, figures 6, 7)

Plecanium lythostrota Schwager, Novara-Exped., Geol. Theil, vol. 2, 1866, p. 194, pl. 4, figs. 4 a-c.

Textularia sagittula Defrance, var. *fugosa* Millett, Journ. Roy. Micr. Soc., 1899, p. 561, pl. 7, fig. 8.

Textularia milletti Cushman, U. S. Nat. Mus., Bull. 71, pt. 2, 1911, . 13, figs. 18 19 (in text); Heron-Allen and Earland, British Antarctic Exped., Zool. vol. 6, 1922, p. 118.

Spiroplectammina milletti Cushman, U. S. Nat. Mus., Bull. 161, 1932, p. 7, pl. 1, figs. 5 a, b.

Textularia lythostrota Lalicker and McCulloch, Allan Hankock Pacific Exped., vol. 6, no. 2, p. 131, pl. 15, figs. 16 a-c.

Test compressed, somewhat longer than broad, subrhomboidal in front view, subrectangular in top view, thickest in apertural chambers, periphery acute; chambers numerous, very low and broad, the upper margin of each one somewhat thickened and coarsely arenaceous, the lower portion concave and less roughened, so that the surface of the test is composed of an alternating series of raised ridges and smoother depressions; wall coarsely arenaceous, composed of calcareous fragments and much calcareous cement; aperture a low narrow opening at the inner margin of the last-formed chamber, in a deep re-entrant.

The initial end of this species is rounded, making it appear much like a *Spiroplectammina*. However, a detailed examination of several specimens of this species with dilute acid shows clearly the initial portion is not planispiral.

This species has been recorded from Pliocene sediments in Kar Nicobar and New Guinea. It has been noted at several localities in the Pacific Ocean. It is present at the following *Atlantis* stations: 2963, 2966, 2971, 2985, 2993 and 2995. These stations are located south of Cuba in water ranging from 190 fathoms to 2125 fathoms in depth.

Textularia lateralis Lalicker

(Plate 4, figures 1 a-c)

Textularia lateralis Lalicker, Smithsonian Misc. Coll., vol. 91, no. 22, 1935, p. 2 pl. 1, figs. 3-5.

Test subtriangular in outline, slightly longer than wide, somewhat compressed, subrhomboidal in end view, periphery subacute to spinose; chambers numerous, about twice as wide as high, usually

rounded at the periphery, but terminating in short, conical spines in some specimens, especially near the initial end, upper margin of each chamber slightly overhanging; sutures distinct, slightly depressed, gently curved in an anterior direction; wall finely arenaceous and rather smoothly finished; aperture a very low opening at the base of the inner margin of the last-formed chamber, with a short lip at the upper edge. Length of figured specimen, 0.52 mm.; width, 0.53 mm.; thickness, 0.26 mm.

Textularia lateralis is present at several stations of the Johnson-Smithsonian Deep-Sea Expedition of the cruise of 1933 in the waters north of Puerto Rico. It has been found at the following *Atlantis* stations: 2959, 2960, 2963, 2966, 2980, 2995, 2999 and 3000.

Textularia luculenta H. B. Brady

(Plate 4, figures 2 a-c)

Textularia luculenta H. B. Brady, Rep. Voy. *Challenger*, Zool., vol. 9, 1884, p. 364, pl. 43, figs. 5-8; Goës, Bull. Mus. Comp. Zool., vol. 29, 1896, p. 42; Flint, Rep. U. S. Nat. Mus., 1897 (1899), p. 284, pl. 29, fig. 3; Heron-Allen and Earland, Trans. Zool. Soc. London, vol. 20, 1915, p. 627; Cushman, U. S. Nat. Mus., Bull. 104, pt. 3, 1922, p. 10, pl. 1, figs. 7-9.

Test compressed, tapering, initial end bluntly pointed, peripheral margins rounded, irregular, or slightly lobulated; chambers numerous, about as high as broad; sutures fairly distinct, marked by fine lines with little or no external depression; wall finely arenaceous with a large proportion of white cement, but smoothly finished; aperture in the earlier stages a curved slit in the normal Textularian position at the base of the last chamber; in the adult it is a round perforation on the distal face of the terminal chamber. Length, up to 2.75 mm.

Textularia luculenta is a very distinctive species. It differs from most species of the genus in that the aperture tends to become terminal in the adult specimen. This shows the trend of evolution of the genus.

T. luculenta is widely distributed in the Atlantic and Pacific Oceans. It has been found in Miocene sediments in Jamaica, B. W. I. It is present at several *Atlantis* stations along the north coast of Cuba, which are as follows: 2975, 2980, 2982 and 2983.

Textularia mexicana Cushman

(Plate 4, figures 3 a-c)

Textularia rugosa Reuss, var., Goës, Bull. Mus. Comp. Zool. Harvard, vol. 29, 1896, p. 43, pl. 5, figs. 4, 5.

Textularia carinata Flint (not d'Orbigny), Rep. U. S. Nat. Mus., 1897 (1899), p. 284, pl. 29, fig. 1.

Textularia mexicana Cushman, U. S. Nat. Mus., Bull. 104, pt. 3, 1922, p. 17, pl. 2, fig. 9; Contr. Cushman Lab. Foram. Ress., vol. 5, 1929, p. 79, pl. 12, fig. 4; Cushman and Barbat, l. c., vol. 8, 1932, p. 33, pl. 5, figs. 3 a, b.

Textularia flabelliformis Galloway & Morrey (not Gümbel), Bull. Amer. Pal., vol. 15, no. 55, 1929, p. 35, pl. 5, figs. 8 a, b.

Test compressed, about one and one-half times as long as broad, the initial end triangular, bluntly pointed, apertural end rounded or slightly angular, periphery sharp, test thickest near the middle, rhomboid in end view; chambers numerous, distinct, wider than high, concave at the lower margin; sutures clear-cut, limbate; wall coarsely arenaceous, roughened, especially over the sutures which are raised and united in the center to form a definite high ridge, especially in the last half of the test; aperture a low arch at the base of the inner margin of the last-formed chamber. Length, up to 1.5 mm.

Textularia mexicana is somewhat similar to *Textularia marginata* Silvestri, from the Pliocene of Italy and the Adriatic Sea, but differs in being much thicker at the apertural end and in having more strongly limbate sutures.

Textularia mexicana is known from Miocene sediments from Jamaica, Venezuela and California. It has been found at a number of stations in the Gulf of Mexico and the Caribbean Sea. It has been found at *Atlantis* stations 2980, 2982, 2983, 2995 and 3000, all of which are located off the north coast of Cuba.

Textularia schencki Cushman and Valentine

(Plate 4, figures 4 a-c)

Textularia cf. *abbreviata* Cushman, Bull. Scripps Inst. Oceanography, Tech. Ser., vol. 1, 1927, p. 136.

Textularia schencki Cushman and Valentine, Contr. Dept. Geol. Stanford Univ., vol. 1, 1930, p. 8, pl. 1, figs. 3 a, b; Lalicker and McCulloch, Allan Hankock Pacific Exped., vol. 6, no. 2, 1940, p. 140, pl. 16, figs. 23 a-c.

Test short and broad, compressed, especially in the early portion, increasing rapidly in width from the pointed initial end, giving the test a broadly triangular form in front view, periphery subacute, except in the last pair of chambers in the adult, which have a rounded periphery, apertural end flat; chambers few, somewhat flattened

except the last pairs in the adult, which are inflated; sutures distinct, only slightly depressed, straight; wall distinctly arenaceous, composed of fine and coarse arenaceous grains cemented with calcareous cement, smoothly finished; aperture a narrow slit at the inner margin of the last chamber. Length of figured specimen, 0.47 mm.; width, 0.31 mm.; thickness, 0.18 mm.

This species has been recorded from the shallow waters off the west coast of California, Mexico and Panama, and from the shallow waters of the Galapagos Islands. It has been found at one locality in the present collections in Gibara Bay, Oriente Province, Cuba, in 30-40 fathoms of water.

Textularia sica Lalicker and Bermúdez, new species

(PLATE 4, FIGURES 5, 6)

Test elongate, lancet shaped, compressed, rectangular in top view, peripheral margins flattened; chambers numerous, low and broad, gradually increasing in height as added, slightly inflated; sutures distinct, depressed, very oblique, making an angle of about 40° with the horizontal axis; wall arenaceous, roughened, composed of fine and coarse grains of siliceous and calcareous material cemented with calcareous cement; aperture a narrow, rather high opening at the inner margin of the last chamber, in a deep re-entrant. Length of holotype, 0.66 mm.; greatest width, 0.31 mm.; thickness, 0.15 mm.

Holotype.—M. C. Z. no. 24; from *Atlantis* station 2999, latitude 23° 10′ N., longitude 81° 10′ W., 230 fathoms.

In addition to the type locality, *Textularia sica* has been found at *Atlantis* stations 2985 and 2995.

TEXTULARIA SUBPLANA Cushman

(PLATE 4, FIGURES 7 a-c)

Textularia subplana Cushman, U. S. Nat. Mus., Bull. 104, pt. 3, 1922, p. 15, pl. 2, fig. 10.

Test about twice as long as wide, expanding gradually from the bluntly rounded initial end, much compresesd, sides flat, periphery flattened at right angles to the sides; chambers increasing slightly in height as added, rectangular in shape; sutures distinct but not depressed; wall arenaceous with a large proportion of cement, very smoothly finished. Length, up to 1.00 mm.

Textularia subplana has been recorded from several *Albatross* stations off the east coast of Florida and off the southeast coast of Brazil. It has been noted at two stations in the shallow waters of the north coast of Cuba.

Vulvulina pennatula (Batsch)

(Plate 4, figures 8, 9)

"Orthoceratia Pupa" Soldani, Test., vol. 1, pt. 2, 1791, p. 99, pl. 108, figures D, E, F.

Nautilus (Orthoceras) pennatula Batsch, Conch. Seesandes, 1791, No. 13, pl. 4, figs. 13 a-d.

Bigenerina pennatula H. B. Brady, Rep. Voy. *Challenger*, Zoology, vol. 9, 1884, p. 373, pl. 45, figs. 5-8; Goës, Bull. Mus. Comp. Zool., vol. 29, 1896, p. 44; Silvestri, Atti Accad. Sci. Acireale, vol. 7, 1896, p. 30; Flint, Rep. U. S. Nat. Mus., 1897 (1899), p. 287, pl. 32, fig. 2; Cushman, U. S. Nat. Mus., Bull. 104, pt. 3, 1922, p. 27, pl. 5, fig. 4.

Vulvulina pennatula Fornasini, Mem. Accad. Sci. Bologna, ser. 5, vol. 10, 1901, p. 14; Lacroix, Bull. Instit. Oceanogr., No. 582, 1931, p. 18; Cushman, Contr. Cushman Lab. Foram. Res., vol. 7, 1931, p. 69, pl. 9, figs. 10-13; Contr. Cushman Lab. Foram. Res., vol. 8, 1932, p. 76, pl. 10, figs. 1-5.

Vulvulina capreolus d'Orbigny, Ann. Sci. Nat., vol. 7, 1826, p. 264, No. 1, pl. 11, figs. 5, 6; Modèles 1826, No. 59; Lacroix, Bull. Instit. Oceanogr. No. 582, 1931, p. 18.

Grammostomum capreolus Parker and Jones, Ann. Mag. Nat. Hist., ser. 3, vol. 11, 1863, p. 93.

Bigenerina capreolus H. B. Brady, Rep. Voy. *Challenger*, Zoology, vol. 9, 1884, p. 372, pl. 45, figs. 1-4; Goës, Bull. Mus. Comp. Zool., vol. 29, 1896, p. 44; Silvestri, Atti Accad. Sci. Acireale, vol. 7, 1896, p. 30; Flint, Rep. U. S. Nat. Mus., 1897 (1899), p. 286, pl. 32, fig. 3; Cushman, U. S. Nat. Mus., Bull. 104, pt. 3, 1922, p. 28, pl. 5, fig. 10.

Grammostomum elegans Parker, Jones, and H. B. Brady, Ann. Mag. Nat. Hist., ser. 4, vol. 8, 1871, p. 170, pl. 11, figs. 121, 123.

Textularia corrugata Costa, Mem. Acc. Sci. Napoli, vol. 2, 1855 (1857), p. 125, pl. 1, fig. 15.

Textularia capreolus Reeve, Conch. System., vol. 2, p. 292, pl. 297, fig. 12.

Test compressed, longer than broad, the microspheric and megalospheric forms showing a great difference in outline, the former usually expanding gradually from a sharply pointed initial end to the widest portion near the apertural end, the latter broadest toward the base and tapering toward the apertural end; earliest chambers planispiral, later ones biserial, numerous, in the megalospheric form followed by one to four uniserial chambers, periphery acute, in the megalospheric form often somewhat spinose, chambers distinct, those of the early portion low, curved, and after the first few, which are spirally coiled, they are biserial, later ones in the adult uniserial, much compressed, fairly high; sutures of the biserial portion usually raised and often somewhat rougher than the body of the chamber, later uniserial chambers with the wall smooth, very finely arenaceous, with much cement and the sutures depressed; aperture of the biserial portion with a low narrow opening at the inner margin of the

chamber, and in the uniserial portion the aperture becomes terminal and elongate. Length, up to 2.50 mm.

Vulvulina pennatula (Batsch) has been noted in the Pliocene sediments of Italy and Sicily. It has been reported from the Adriatic Sea, the Atlantic Ocean, and the Caribbean Sea. It has been found in the following *Atlantis* stations off the northeast coast of Cuba: 2971, 2980, 2982 and 2988.

TABLE OF STATIONS

Atlantis station 2953, Feb. 10, 1938.
Latitude 21° 47′ 30″ N., longitude 84° 32′ 30″ W., 615 fathoms.

Atlantis station 2959, Feb. 15-16, 1938.
Latitude 21° 17′ N., longitude 83° 06′ W., 2050 fathoms.

Atlantis station 2960, Feb. 18, 1938.
Latitude 22° 07′ N., longitude 81° 08′ 30″ W., 270 fathoms.

Atlantis station 2963, Feb. 25, 1938.
Latitude 22° 12′ N., longitude 81° 10′ W., 190 fathoms.

Atlantis station 2966, Feb. 26, 1938.
Latitude 20° 47′ 05″ N., longitude 80° 24′ 05″ W., 2125 fathoms.

Atlantis station 2971, March 6, 1938.
Latitude 20° 34′ N., longitude 74° 24′ W., 810 fathoms.

Atlantis station 2975, March 7, 1938.
Latitude 21° 13′ N., longitude 75° 39′ W., 1015 fathoms.

Atlantis station 2977, March 9, 1938.
Latitude 21° 42′ N., longitude 76° 59′ W., 1175 fathoms.

Atlantis station 2980, March 10, 1938.
Latitude 22° 48′ N., longitude 78° 48′ W., 225 fathoms.

Atlantis station 2983, March 12, 1938.
Latitude 23° 11′ N., longitude 79° 12′ W., 260 fathoms.

Atlantis station 2988, March 14, 1938.
Latitude 23° 15′ N., longitude 78° 57′ W., 380 fathoms.

Atlantis station 2982, March 11, 1938.
Latitude 22° 48′ N., longitude 78° 50′ 30″ W., 210 fathoms.

Atlantis station 2993, March 15, 1938.
Latitude 23° 24′ N., longitude 80° 44′ W., 580 fathoms.

Atlantis station 2995, March 16, 1938.
Latitude 23° 24′ N., longitude 81° 00′ 30″ W., 605 fathoms.

Atlantis station 3000, March 21, 1938.
Latitude 23° 10′ N., longitude 81° 29′ W., 160 fathoms.

Bermúdez station R1, La Chorrera, Habana, Cuba, 2 to 5 fathoms.

Bermúdez station R5, Claude, Matanzas Beach, Cuba, 40 fathoms.

Bermúdez station R6, off Punta Seboruco, north coast of Matanzas, Cuba, 20 fathoms.

Bermúdez station R8, off Bueyvaca River, Matanzas Bay, Cuba, 25 fathoms.

Bermúdez station R13, off Cuban Distilling Company, Matanzas Bay, Cuba, 60 fathoms.

Bermúdez station R20, Camacho, Matanzas Bay, Cuba, 15 fathoms.

Bermúdez station R22, Varadero Beach, north coast of Matanzas, Cuba, 15 fathoms.

Bermúdez station R28, sand near Boca de Buyvaca, Matanzas Bay, Cuba.

EXPLANATION OF PLATE I

1 *a-c*. *Bigenerina lytta* Lalicker and Bermúdez, n. sp. × 50. Holotype.
2 *a, b*. *Bigenerina nodosaria* d'Orbigny, var. *textularioidea* (Goës). × 27.
3, 4. *Bigenerina perna* Lalicker and Bermúdez, n. sp. × 33. 3, Paratype; 4, Holotype.
5, 6. *Spiroplectammina gramen* (d'Orbigny). × 50. 5, megalospheric form; 6, microspheric form.
7 *a-c*. *Textularia agglutinans* d'Orbigny. × 50.
a, front views; *b*, apertural views; *c*, side views. Figures drawn by Ann Shepard.

EXPLANATION OF PLATE II

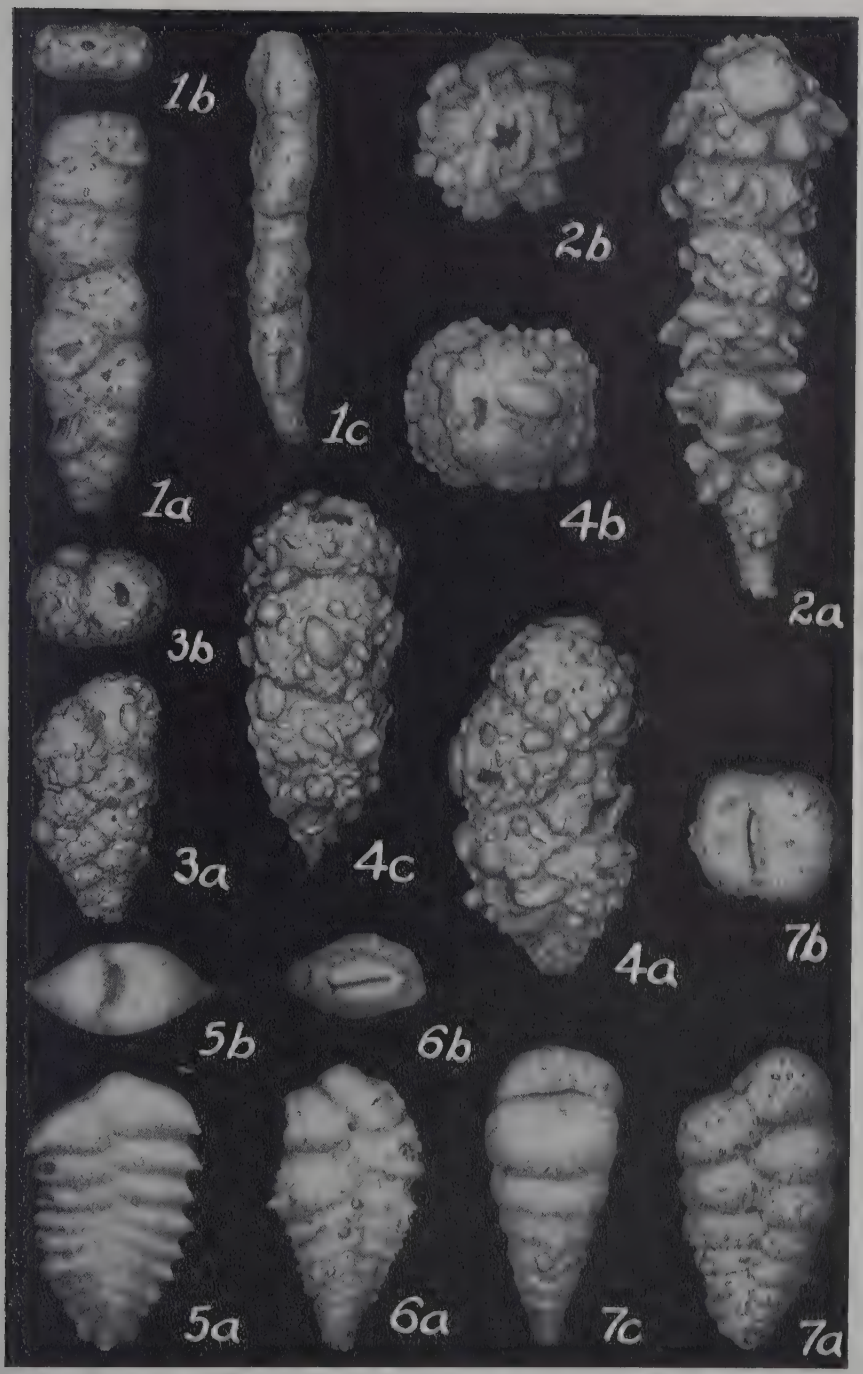
1 *a-c*. *Textularia albatrossi* Cushman. × 33.
2, 3. *Textularia calva* Lalicker. × 33. 2, microspheric form; 3, megalospheric form.
4 *a-c*. *Textularia candeiana* d'Orbigny. × 50.
5, 6. *Textularia caribaea* d'Orbigny. × 40.
7 *a-c*. *Textularia catenata* Cushman. × 60.
a, front views; *b*, apertural views; *c*, side views. Figures drawn by Ann Shepard.

EXPLANATION OF PLATE III

1 *a-c*. *Textularia concava* (Karrer). × 60.
2 *a-c*. *Textularia conica* d'Orbigny. × 70.
3 *a-c*. *Textularia corrugata* Heron-Allen and Earland. × 40.
4 *a-c*. *Textularia flintii* Cushman. × 33.
5 *a-c*. *Textularia flintii* Cushman, var. *curta* Cushman. × 60.
6, 7. *Textularia lythostrota* (Schwager). × 40.
a, front views; *b*, apertural views; *c*, side views. Figures drawn by Ann Shepard.

EXPLANATION OF PLATE IV

1 *a-c*. *Textularia lateralis* Lalicker. × 50.
2 *a-c*. *Textularia luculenta* H. B. Brady. × 40.
3 *a-c*. *Textularia mexicana* Cushman. × 33.
4 *a-c* *Textularia schencki* Cushman and Valentine. × 70.
5, 6. *Textularia sicca* Lalicker and Bermúdez n. sp. × 60. 5, Holotype, a microspheric form; 6, Paratype, a megalospheric form.
7 *a-c*. *Textularia subplana* Cushman. × 33.
8, 9. *Vulvulina pennatula* (Batsch). × 27. 8, microspheric form; 9, megalospheric form.
a, front views; *b*, apertural views; *c*, side views. Figures drawn by Ann Shepard.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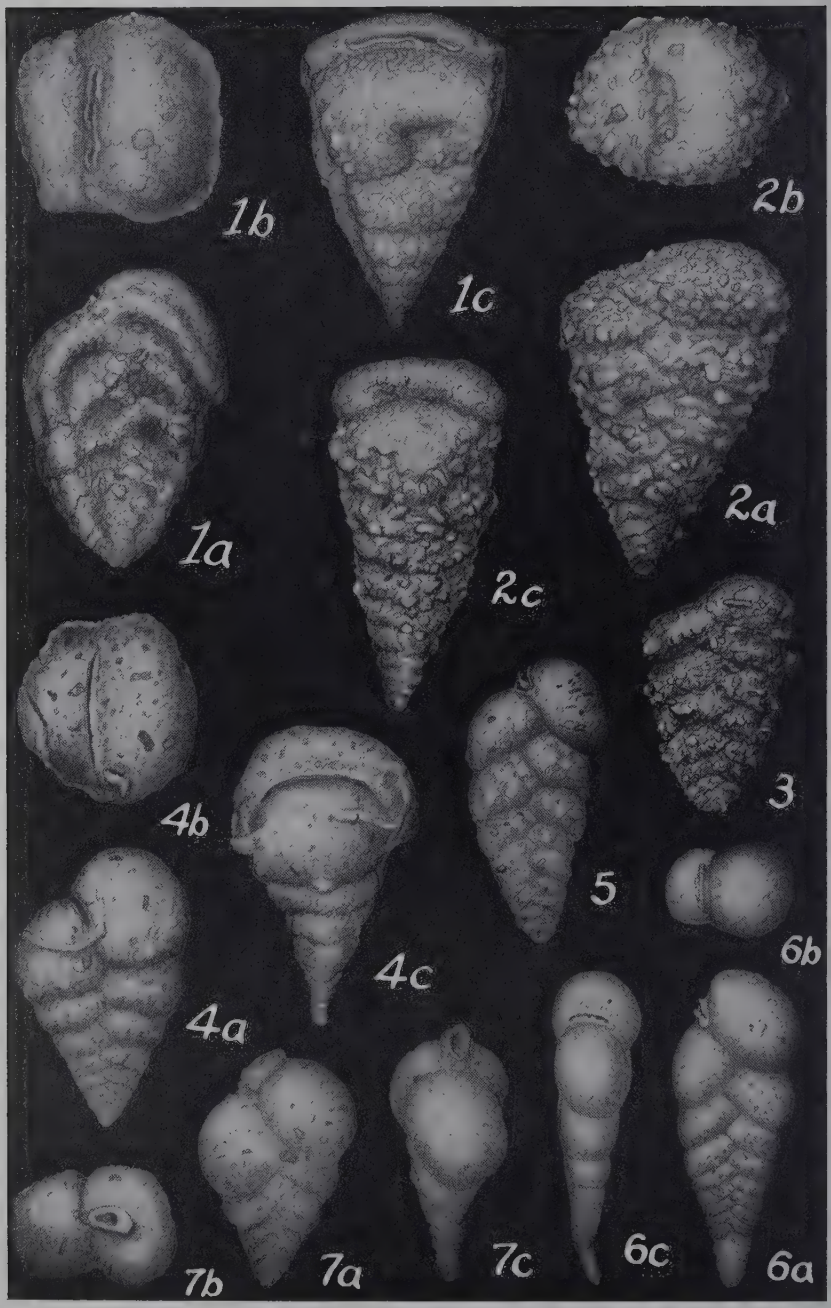

Lalicker & Bermudez: *Foraminifera of the Family Textulariidae.*

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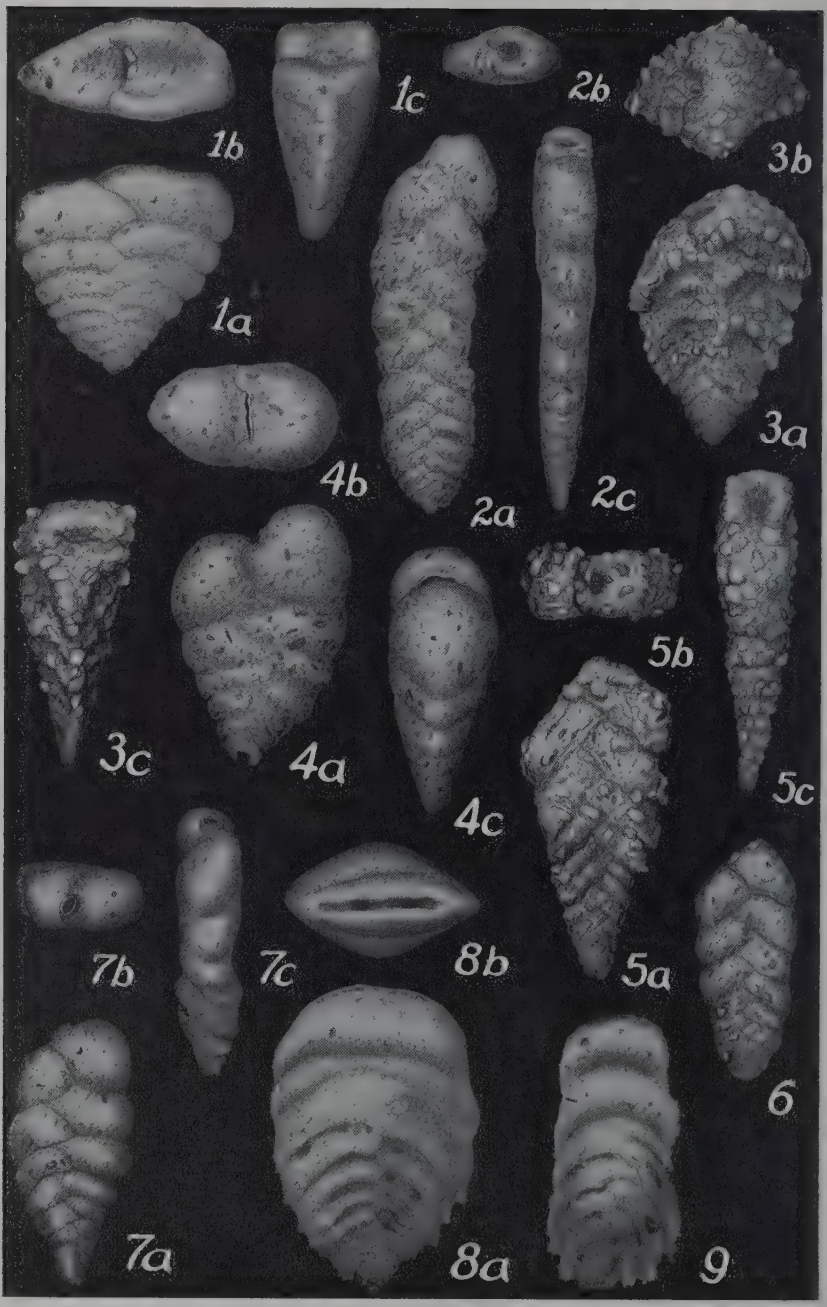

LALICKER & BERMUDEZ: *Foraminifera of the Family Textulariidae.*

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Proceedings of the American Physiological Society
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Vitamins A in invertebrate eyes. George Wald.[1] *The Biological Laboratories of Harvard University, Boston, Mass., and the Woods Hole Oceanographic Institution, Woods Hole, Mass.* (Contribution No. 284.)

The retina of the squid, *Loligo pealii*, contains 1–2 μgm. of vitamin A_1, and about 3 times this quantity (measured as relative extinction in the antimony chloride reaction) of retinene$_1$ (cf. Wald. J. Gen. Physiol. **22:** 391, 1939). No trace of these or other carotenoids was found in other squid tissues.

The quantity of vitamin A remains constant in all conditions of light and darkness. Vitamin A does not appear therefore to participate directly in the visual processes.

About 15 units (relative) of retinene can be extracted with benzine in darkness. A further 7 units is released on exposure of the live squid or of the isolated retina to light. About 120 units of retinene is stored in a photostable retinal complex from which it can be extracted only with polar organic solvents like chloroform.

The squid apparently possesses therefore the simple visual cycle, visual purple $\underset{\longleftarrow}{\overset{\text{light}}{\rightleftharpoons}}$ retinene + (protein?). The term visual purple is used here in its generic sense. Though measurements of spectral sensitivity (Hess, Hartline) show that the squid possesses a photopigment comparable with rhodopsin, attempts to extract it have so far failed. The deep purple color of the squid retina, sometimes ascribed to visual purple, is due to a photostable, alkali-soluble, probably melanoid pigment. Other than screening the retinal cells, this probably plays no role in vision.

In the vertebrate rods retinene occupies a position symmetrical with that of vitamin A. In the squid, retinene entirely preempts the vitamin A function. It is therefore itself a vitamin A — vitamin A_3.

The eyes of green and fiddler crabs (*Carcinus maenas* and *Uca pugnax*) also contain high concentrations of vitamin A_1. No trace of retinene has been found in these tissues.

There is therefore no discontinuity between vertebrates and invertebrates in the occurrence and utilization of vitamins A in the eye. Failure heretofore to identify vitamins A in invertebrates may be ascribed to their low capacity for storing these substances.

[1] This research was supported in part by a grant from the Josiah Macy, Jr. Foundation.

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MEMORIAS

DE LA

SOCIEDAD CUBANA DE HISTORIA NATURAL

"FELIPE POEY"

REPORTS ON THE SCIENTIFIC RESULTS OF THE ATLANTIS EXPEDITIONS TO THE WEST INDIES, UNDER THE JOINT AUSPICES OF THE UNIVERSITY OF HAVANA AND HARVARD UNIVERSITY

THE ECHINODERMS

(OTHER THAN HOLOTHURIANS)(*)

By Hubert Lyman Clark

INTRODUCTION

The collection of Echinoderms made by the *Atlantis* during her visit to Cuba in 1938 was a notable one, containing representatives of at least 140 species, of which about one-fifth were new to science. But during the second visit in 1939, the collections were truly surprising both in quantity of material and in number of species. Most of the forms taken on the first trip were secured in larger numbers in 1939 and numerous species were added to the list. This report includes all of the more than 6000 Echinoderms taken during the two cruises, other then the holothurians, a report on which has been prepared by Dr. Elizabeth Deichmann.

(*) Contribution No. 285 of the Woods Hole Oceanographic Instituttion.

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There can be no doubt that the *Atlantis* material constitutes one of the most extensive collections of Echinoderms that has ever been made in the West Indian region. The only comparable accumulation is that secured by the *Blake* during her three cruises in 1877-1880, which covered a vastly greater geographical area than that visited by the *Atlantis*. The reports on the collections made by the *Blake* were prepared by half a dozen scientists of whom at least three were engrossed in reports on the even more extensive and exciting collections made just previously by H. M. S. *Challenger*. As a result, the *Blake* collections failed to receive the attention they deserved. The various reports show such a lack of uniformity, and include so many species not taken by the *Blake,* or taken by the *Blake* outside the West Indian region (for it should be remembered that most of the 1880 collecting was in the western Atlantic, north of Georgia), it is not easy to determine the exact extent of the West Indian collections. The published reports list well over 300 species but careful examination brings out the fact that nearly one-fourth of these were taken outside of the West Indian region, many by vessels other than the *Blake*. The actually West Indian collections of that vessel apparently included 246 species.

The study of the stalked crinoids was never completed but P. H. Carpenter's preliminary report, and the catalog of the M. C. Z. collections, show that 7 species were taken. The comatulids were also sent first to Carpenter, the English authority on crinoids, but unfortunately he died before preparing his report. They were then sent to Clement Hartlaub, a German zoologist, who after twenty years delay, published in 1909 a voluminous report, discussing 31 species. At least 18 of these however were not taken in the West Indies by the *Blake*. Mr. Austin Hobart Clark, our final authority on the group, tells me that Hartlaub's 13 *Blake* West Indian species really represent 22 now recognized forms. We are therefore justified in saying that the *Blake* took 29 species of crinoids in the West Indian region. The sea-stars were reported on by E. Perrier, the well known French student of the group, whose final memoir lists 54 species but 4 of these were not taken by the *Blake* in the West Indian region. The brittle-stars were a huge collection and received but scanty attention from Mr. Lyman whose monumental and invaluable report on the *Challenger* ophiurans had just been published.

In his brief report on the *Blake* collection, he lists no fewer than 137 species but 37 of these were from outside the West Indian region,

a number from collections other than those of the *Blake*. Mr. Agassiz's memoir on the Echini was much the best of the Echinoderm reports, discussing 55 species of which 10 were not taken in the West Indies. The proportion of non-*Blake* species reaches its maximum in Théel's report on the holothurians which includes comments on 43 species but only 22 of these were taken by the *Blake* in the West Indian region.

The *Blake* collections then may be tabulated thus:

	Species reported	Non-West Indian	West Indian
Crinoids	38	18	20 (now 29)
Asteroids	54	4	50
Ophiurans	137	37	100
Echini	55	10	45
Holothurians	43	21	22
Totals	327	90	237 (now 246)

As compared with this, the *Atlantis* in her two cruises took 224 species as follows.

Crinoids	22	species
Asteroids	64	
Ophiurans	75	
Echini	40	
Holothurians	23	(according to Dr. Deichmann)
	224	species

When it is realized over how much more extensive an area the collections of the *Blake* were made, from the Tortugas and Yucatan on the northwest to Grenada and Barbados on the southeast, it is not surprising that her total number of species exceeds that of the *Atlantis*, but when it is further explained that 6 of her crinoids, 14 of her asteroids, 48 of her ophiurans and 9 of her echini were secured *only* in the Lesser Antilles from St. Kitts southward, the number of species taken by the *Atlantis* in Cuban waters is truly extraordinary, 224 as against the *Blake's* 169.

Disregarding the holothurians, the 201 species collected by the *Atlantis*, included 33 new to science. In addition, many species discovered by the *Blake* but represented in her collections by a single specimen, or by a very few, have now been secured again by the *Atlantis* and usually in large and admirably preserved series. These

series in several cases are of the greatest importance in revealing the growth-stages from very young to adult, occasionally showing the lack of validity of certain nominal species.

Congratulations and praise are certainly due Messrs. W. C. Schroeder and L. Howell Rivero for their success as collectors and their skill in the preservation and care of echinoderms. In presenting this report I desire to express my hearty thanks to Mr. Schroeder and Dr. Carlos Aguayo for the great privilege of studying so notable a collection.

CRINOIDEA

The crinoids form a conspicuous part of the collection for there are 759 specimens, of which more than a third are the large and showy stalked pentacrinids, long known from Cuban seas. Another third consists of the apparently wide-spread and very common but showy comatulid, *Crinometra insculpta,* and half the remaining specimens are divided between the common, small *Horaeometra duplex* and the larger and more conspicuous *Neocomatella pulchella.* Altogether there are 22 species represented of which 6 were new to science. Of these six, 5 belong in the single genus Caryometra of the family Antedonidae, and as they are all small and mostly badly broken, Mr. Austin Hobart Clark has very kindly given them the benefit of his extensive knowledge and experience, and at my request, has published descriptions and figures of each.(1) For this service and for many other kindnesses, and much help, always cheerfully and promptly given, I am glad to offer here my very sincere thanks. The other new species is a pentacrinid, represented by a number of specimens, of the genus Endoxocrinus, easily seen to be quite different from the common Cuban spefies. It is worthy of note that stalked crinoids were taken at 20 stations and comatulids at 57. At 11 stations both stalked forms and comatulids occurred; at St. 3303, three species of stalked crinoids and five of comatulids were taken and at St. 3326, two species of stalked crinoids were associated with four comatulids. These two stations are on opposite sides of Cuba (one, 3303, is west of Havana, the other west of Cienfuegos) but they are at practically the same depth, 260-265 fms.

(1) 1940. Mem. Soc. Cubana Hist. Nat., *14* (2), pp. 139-160.

STALKED CRINOIDS

Family PENTACRINIDAE

Neocrinus blakei

Pentacrinus blakei P. H. Carpenter, 1882. Bull. M. C. Z., *10*, p. 172.
Neocrinus blakei A. H. Clark, 1923. Jour. Wash. Acad. Sci., *13*, p. 11.

This slender and fragile sea-lily is represented by a dozen specimens taken on both the northern and southern coasts of Santa Clara, in 290-320 fms., and at the northwestern corner of Camaguey, in 220-225 fms. The station numbers are 2980B, 3323, 3324, 3435 and 3437.

Neocrinus decorus

Pentacrinus (*Neocrinus*) *decorus* Wyville Thomson, 1864. Intellectual Observer, no. XXXI, p. 7.
Neocrinus decorus A. H. Clark, 1923. Jour. Wash. Acad. Sci., *13*, p. 11.

This much better known Neocrinus was not met with in 1938 but in 1939, 26 specimens were taken at Playa Baracoa, northern coast of Havana Province in 230-260 fms.; off Bahia de Matanzas, northern coast of Matanzas Province in 190-215 fms.; and, in company with the preceding species, at Bahia de Cochinos, on the southern coast of Santa Clara Province, in 290-320 fms. The station numbers are 3302, 3303, 3323, 3467, 3479, 3480 and 3482.

Endoxocrinus parrae

Encrinus parrae Guerin, 1835. Dict. Hist. Nat., *3*, p. 49.
Endoxocrinus parrae A. H. Clark, 1908A. Proc. Biol. Soc. Wash., *21*, p. 151.

This is the most common and variable of the West Indian stalked crinoids. The *Atlantis* brought back some 225 specimens taken at eleven stations on both the northern and southern coasts of Cuba. It is interesting to note that they were usually associated with *Neocrinus decorus*. The smallest specimen has arms scarcely 50 mm. long (from base of calyx) and stalk hardly 1 mm. in diameter. The largest have arms 115-120 mm. long and stalks 5 mm. in diameter. The bulk of the material is from the vicinity of Bahia de Matanzas, east of Havana, in 145-240 fms. but many specimens were taken west of Havana, off Playa Baracoa, in 230-260 fms. A single spe-

cimen is from "off Caibarien", on the northeastern coast of Santa Clara, in 295 fms. All of the specimens from the southern side of the island were taken in the Bahia de Cochinos, Santa Clara, in 265 fms. The station numbers are 2999, 3302, 3303, 3326, 3439, 3465, 3467, 3478, 3480 and 3482.

Endoxocrinus prionodes[1] sp. nov.

(Plate 1)

Closely related to *E. parrae* but distinguished by certain features of the stem and basal parts of the arms. Stem of the holotype 150 mm. long, slender, rather more than 3 mm. in diameter, rounded pentagonal, approaching cylindrical. There are 8 internodes, each with 12-14 segments, the sutures between which are simple and straight. Cirri about 25 mm. long, nearly cylindrical but slightly expanded basally and a trifle compressed at tip, of about 30 segments, of which the eighth to eleventh are longest, as long as thick or even longer; distally the lower side of each segment carries faint, low tubercles of which one is near the distal margin and one near the proximal; as the segments become smaller the tubercles increase a little in size and double in number until on the distal joints there are 2 on each margin of the segment and on the outermost segments these pairs form very low transverse ridges. Tubercles and ridges are faint and minute so that seen from the side the cirri are scarcely serrate even at tip.

Calyx 6 mm. in diameter at base; 16 mm. above the II Br series. Arms 32, 80-90 mm. long. First two postradial ossicles united by syzygy; the second is axillary. II Br series 2 (1 + 2). III Br series 3 (1 + 2), usually developed externally only but in a few cases developed internally also on one side. No further division series. First two brachials united by syzygy. Elements of division series and first 8-10 brachials wall-sided and more or less appressed, the surface (especially of the axillaries) convex but not really swollen. Elements of the III Br series and the first 3-6 basal brachials with the distal corners projecting more or less conspicuously. Beginning with the third or fourth, the following 6-10 brachials have the distal margin everted at middle into a more or less conspicuous projection, usually spine-like but often flattened and wide at tip. Seen from the side, these projections give the basal part of the free arms a conspicuously serrated appearance. Distal brachials and pinnules as in *parrae* but the pinnules are a little more flattened and more definitely prismatic. Color (dry): cream color, becoming nearly white distally but more gray on calyx; stem nearly ivory-white. Holotype: M. C. Z. No. 1000, from St. 3438, off Caibarien, northern coast of Santa Clara Province, Cuba, 265 fms.

(1) πριονώδης = *serrated*, in reference to the appearance of the basal portions of the arms.

There are 3 other specimens from St. 3438, all of about the same size and appearance as the one described. A similar specimen was taken at St. 3323, which is on the southern coast of Cuba in the Bahia de Cochinos, 290-320 fms. A smaller specimen was secured at St. 3303, off Playa Baracoa, west of Havana, 260 fms. Finally 3 young individuals were taken at St. 3326, in the Bahia de Cochinos, 265 fms., which are of special interest because of their small size. The smallest has 12 arms about 40 mm. long, with the projections on the lower brachials just becoming evident. A second, with 14 arms, about 50 mm. long, shows the everted brachial projections clearly. Neither of these specimens have retained any cirri. The third specimen has lost several arms on one side but there were at least 17 and probably more than 20; they are about 60 mm. long. A number of cirri are present; one complete one has 22 segments, the distal ones showing the tubercles as described above. The internodes of the stem have 11 or 12 segments. These 3 youthful specimens are distinctly light yellow, the stem more nearly white. Many specimens of *E. parrae* were taken at St. 3326 but these young *prionodes* are easily distinguished.

Family Bourgueticrinidae

Bythocrinus conifer

Rhizocrinus conifer A. H. Clark, 1909. Proc. U. S. Nat. Mus., *36*, p. 674.
Bythocrinus conifer A. H. Clark, 1917. Jour. Wash. Acad. Sci., *7*, p. 392.

There is a very fine specimen of this fragile crinoid, 160 mm. high, 110 of which is stalk, from St. 2989, in Nicholas Channel, off the northern coast of Santa Clara, 360 fms. No specimens were taken during the 1939 cruise.

Democrinus rawsonii

Rhizocrinus rawsonii Pourtalès, 1874. Ill. Cat. M. C. Z. No. 8, p. 27.
Democrinus rawsonii A. H. Clark, 1917. Jour. Wash. Acad. Sci., *7*, p. 392.

A stalk with calyx, but no arms, still attached at the upper end and several broken "rootlets" at the lower, was taken in 1938 at St. 2963, in 180-190 fms., in Bahia de Cochinos, on the southern coast of Santa Clara. It is nearly 200 mm. long and about 2 mm. in diameter thru the calyx, and also near the lower end; it is appreciably smaller below the calyx. No specimens were met with in 1939.

Monachocrinus caribbeus

Bathycrinus caribbeus A. H. Clark, 1908. Bull. M. C. Z., *51*, p. 235.
Monachocrinus caribbeus A. H. Clark, 1917. Jour. Wash. Acad. Sci., *7*, p. 390.

A single stalkless calyx and arms, about 50 mm. in length, is in the 1938 collection, which appears to represent this species. It was taken at St. 2975, off Punta Lucrecia, Oriente Province, Cuba, in 1015 fms. Nothing similar was met with during the 1939 cruise.

COMATULIDS

Family Comasteridae

Neocomatella pulchella

Antedon pulchella Pourtalès, 1878. Bull. M. C.Z., *5*, p. 216.
Neocomatella pulchella A. H. Clark, 1921. Univ. Iowa, Stud. Nat. Hist., *9*, No. 5, p. 9.

This common and long-known comatulid was found by the *Atlantis,* during both cruises, on both the northern and southern coasts of Cuba, but on the southern coast it was taken only in the Bahia de Cochinos, 215-265 fms. and on the northern coast, tho several were collected off Playa Baracoa, west of Havana, in 230-260 fms., and 3 at Caibarien, Santa Clara, in 265 fms., the bulk of the material was secured off Bahia de Matanzas, in 145-240 fms. Altogether 69 specimens were taken, ranging from a young one, 6 mm. across the disk with arms 60 mm. long to adults 15-17 mm. across disk and arms exceeding 100 mm. The station numbers are 2962a, 2999, 3302, 3303, 3326, 3438, 3463, 3465, 3466, 3478, 3479 and 3480.

Family Thalassometridae

Stylometra spinifera

Antedon spinifera P. H. Carpenter, 1881. Bull. M. C. Z., *9*, p. 158.
Stylometra spinifera A. H. Clark, 1908. Bull. M. C. Z., *51*, p. 245.

This striking comatulid was not taken during the 1938 cruise but was found several times the following year, on the north shore; once off Playa Baracoa, west of Havana in 260 fms. where it seems to be common as 10 specimens were taken; and later off Bahia de

Matanzas, in 190-200 fms., where two small specimens and one large one, with 29 arms nearly 100 mm. long, were dredged. The station numbers are 3303, 3465, 3466 and 3482.

Horaeometra duplex

Antedon duplex P. H. Carpenter, 1888. *Challenger* Comatulae, p. 212.
Horaeometra duplex A. H. Clark, 1918. *Siboga* Comatulids, p. 160.

This pretty, little comatulid was taken during both cruises but only on the north coast. A single specimen occurred at Playa Baracoa, Havana Province, in 260 fms. and another was found off Caibarien, Santa Clara, at the same depth. But off Bahia de Matanzas, Horaeometra is evidently very common for 42 specimens were taken there in 145-240 fms. A single small specimen bears the label, "off north coast of Cuba, 100 fms. ±". The station numbers are 2999, 3303, 3437, 3465, 3466, 3467, 3478, 3479 and 3480.

Family Charitometridae

Crinometra granulifera

Antedon granulifera Pourtalès, 1878. Bull. M. C. Z., *5*, p. 215.
Crinometra granulifera A. H. Clark, 1923A. *Ingolf* Crinoidea, p. 40.

There are 15 comatulids to be referred to this little known species, of which 8 were taken at Playa Baracoa, Havana Province, in 260 fms., and the remainder off Bahia de Matanzas, in 145-240 fms. One was taken in 1938, the rest in 1939. These specimens have been compared with Pourtalès type (M. C. Z. 267) and there is no doubt of their identity. The only noticeable difference is that in the type the distal cirrus joints are distally conspicuously wider than proximally, while in the *Atlantis* material the projection of the lower distal margin is not so conspicuous. But the *Atlantis* specimens show some diversity in this detail. The type has the arms about 100 mm. long; several of the Cuban specimens are larger, with arms 125-150 mm. The type still retains a distinct dull purplish-brown color while the *Atlantis* specimens are much more nearly white, especially when dry. The stations where *granulifera* was taken are numbered 2999, 3303, 3465, 3478 and 3482.

Crinometra insculpta

A. H. Clark, 1909. Proc. U. S. Nat. Mus., *36*, p. 646.

Judging from the *Atlantis* collections, this is by far the most abundant and widespread of Cuban comatulids. In 1938, it was taken at 13 stations (Nos. 2950, 2980, 2980A, 2980B, 2982A, 2982B, 2982C, 2983, 2983A, 2984, 2987, 2999 and 3000) all between the Bahama Islands and Santa Clara and Matanzas Provinces, Cuba, in 170-300 fms. In 1939, *insculpta* was taken at 16 stations, with the same bathymetrical range, chiefly along the northern coast of western Cuba, but also as far east as Puerto Tanamo on the northern coast of Oriente, and at the Bahia de Cochinos, on the southern coast of Santa Clara. (Nos. 3303, 3326, 3372, 3388, 3425, 3430, 3431, 3432, 3434, 3435, 3436, 3438, 3466, 3467, 3478 and 3482.) In all, 272 specimens were secured, several still attached to the sponges upon which they apparently often live (*not, feed*). Most of the specimens still retain some trace of a bright yellow color which is very marked in many specimens and was apparently the normal color in life; in large specimens the calyx and base of the arms is darker and duller, an indistinctive gray-brown. Dry material is often more or less bleached, sometimes nearly white. The size of the specimens at hand ranges from about 8-10 mm. across the disk, with arms 50 mm. long, more or less, to big adults 20-25 mm. across the disk, with arms nearly or quite 200 mm. long. There is no little diversity in the sculpturing and ornamentation of the calyx and arm-bases but on the whole, the species characters are well maintained.

Crinometra pulchra

A. H. Clark, 1909. Proc. U. S. Nat. Mus., *36*, p. 644.

A small comatulid, 10 mm. thru the calyx, with arms about 90-100 mm. long, lacking cirri, looks like a young Crinometra but is clearly not either *granulifera* or *insculpta*. Mr. Austin H. Clark has kindly identified it for me as a young specimen of this species. It was taken at St. 3326, Bahia de Cochinos, south side of Santa Clara Province, in 265 fms.

Family Antedonidae

Compsometra nuttingi

A. H. Clark, 1936. Proc. U. S. Nat. Mus., *83*, p. 246.

A single small and badly damaged comatulid taken in 1939 at St. 3412, off Camaguey Province, northern coast, 235 fms., has been identified by Mr. A. H. Clark as a second specimen of this rare species.

Caryometra alope

A. H. Clark, 1940. Mem. Soc. Cubana Hist. Nat., *14* (2), p. 156.

This long-armed, delicate comatulid seems to be rather uncommon, tho it was taken on both cruises. It occurs along the northern coast of Camaguey, Santa Clara and Matanzas Provinces, in 195-425 fms., and also on the southern coast of the island at the Bahia de Cochinos, in 185 fms. The largest and best preserved of the 9 specimens has arms 75-80 mm. long. The stations where *alope* was taken are 2982, 2982C, 2989, 2990A, 3320, 3406, 3463 and 3469. The holotype M. C. Z. No. 1010 is from St. 2989, in Nicholas Channel, northern coast of Santa Clara, in 360 fms.

Caryometra atlantidis

A. H. Clark, 1940. Mem. Soc. Cubana Hist. Nat., *14* (2), p. 148.

This dainty little comatulid is apparently common on both coasts of Cuba, as it was taken by the *Atlantis* in 1938 and even more frequently in 1939. It was found at no fewer than 18 stations, in depths of 200-290 fms. (Nos. 2960, 2963D, 2983A, 3385, 3386, 3389, 3391, 3392, 3393, 3394, 3401, 3404 3405, 3412, 3413, 3416, 3421, 3427.) It is extremely delicate and fragile and all of the 44 specimens are badly damaged. Not one is approximately whole but it is possible to determine that large specimens have the disk 3 or 4 mm. across, the arms 90-100 mm. long, and the thread-like cirri 25-30 mm. long. The color is apparently white or pale yellowish. The holotype, M. C. Z. No. 1011, is from St. 3394, in the Old Bahama Channel, off Camaguey, in 200 fms.

Caryometra lisa

A. H. Clark, 1940. Mem. Soc. Cubana Hist. Nat., *14* (2), p. 154.

This apparently uncommon comatulid was taken once in 1938 but it was not seen in 1939. The two specimens are in fairly good condition, the disk 3 or 4 mm. across, the arms 60 mm. long, the cirri 25-30 mm. but stouter than in the preceding species. They were taken at St. 2990, off Puerto Sagua la Grande, Nicholas Channel, Santa Clara Province, in 390 fms. The holotype is M. C. Z. No. 1012.

Caryometra monilicirra

A. H. Clark, 1940. Mem. Soc. Cubana Hist. Nat., *14* (2), p. 144.

This seems to be also a rare species for it was not taken in 1938 and only once in 1939. A single specimen, with arms about 25 mm. long and cirri 7 or 8 mm., was dredged at St. 3435, off Caibarien, northern coast of Santa Clara Province, in 255 fms. It is easily distinguished by the curious short, almost moniliform cirri. The holotype is M. C. Z. No. 1013.

Caryometra spinosa

A. H. Clark, 1940. Mem. Soc. Cubana Hist. Nat., *14* (2), p. 151.

This is another scarce novelty taken only in 1939 and then only in the Bahia de Cochinos on the southern coast of Santa Clara Province, in 185-265 fms. (Sts. 3320 and 3326). The more or less everted, minutely spinose upper margin of the brachials and the extremely long (35-45 mm.) cirri are distinctive. In none of the 5 specimens are the arms (not even one) approximately whole but the fragments indicate they were at least 75-80 mm. long in life. The holotype is M. C. Z. No. 1014 from St. 3320, not 2990 as stated in A. H. Clark's paper. His species was not taken at 2990.

Trichometra cubensis

Antedon cubensis Pourtalès, 1869. Bull. M. C. Z., *1*, p. 356.
Trichometra cubensis A. H. Clark, 1923. *Ingolf* Crinoidea, p. 43.

Altho the *Atlantis* did not meet with this comatulid in 1938, the following year she secured a very good specimen at St. 3305, off Playa Baracoa, Havana Province, in 330 fms. This individual has arms about 50 mm. long and a large tuft of cirri 12-15 mm in length.

Family Atelecrinidae

Atelecrinus balanoides

P. H. Carpenter, 1881. Bull. M. C. Z., *9*, p. 166.

This notable comatulid was taken once by the *Atlantis* in 1938 but no specimens were secured in 1939. It is apparently rare or local. The 5 specimens at hand were all secured at St. 2990, off Puerto Sagua la Grande, Nicholas Channel, Santa Clara Province, in 390 fms., along with *Caryometra lisa*. Save for the fact that all the cirri are lacking and the arms are more or less broken distally the specimens are in good condition and show the specific characters well. The largest is about 7 mm. in diameter thru the calyx. In smaller specimens the broken arms are 50 mm. long, but in life they were probably 75. All the specimens are white.

Atelecrinus pourtalesi

A. H. Clark, 1907. Proc. U. S. Nat. Mus., *33*, p. 155.

A badly damaged Atelecrinus from St. 3341 is obviously different from the preceding and apparently represents this species. The centrodorsal is rather more than 3 mm. long and rather less than 3 mm. in diameter at the base. The horseshoe shaped ridges around the bases of the cirri are more conspicuous and the tips more projecting than in *balanoides*, as Carpenter pointed out, so that the general appearance is noticeably different from that of the other species. The difference in the form of I Br 1 does not seem to me as striking as Carpenter suggests but only more and better preserved specimens can determine its value as a specific character. Unfortunately the type and only known specimen of *pourtalesi* was among the comatulids that were sent to Carpenter and then to Hartlaub, and were never returned by the latter, who reported that some specimens were accidentally destroyed.

In the *Atlantis* specimen, the basal portions of 5 cirri are present, the longest is 9 mm. and made up of 6 segments, of which the first is about as long as thick, the second is twice as long, the third still longer and the sixth is 1.5 mm. long and about .3 mm. thick at middle but somewhat thicker at the ends. Compared with the holotype of *balanoides* which still has several fragments of cirri associated with it, the cirri of *pourtalesi* are noticeably more slender and cylindrical; they are not at all flattened (at least basally) as they are noticeably

in *balanoides*. The arms of the *Atlantis* specimen are badly broken and only the basal brachials are present, save in one case where about 40 mm. of an arm is still attached to the calyx. As in *balanoides* syzygial pairs alternate with single brachials in the basal portion of the arm but distally the syzygies are less numerous and regular. The pinnules seem to be just like those of *balanoides*.

This unique and highly interesting specimen was taken off the southern coast of Santa Clara Province in the Golfo Cazones in 310-425 fms. No other crinoids were taken at that station.

ASTEROIDEA

The collection of sea-stars accumulated by the *Atlantis* in her two cruises is easily the largest and most important ever made in the West Indies. There are altogether 857 specimens representing 64 species, of which 16 appear to be new to science. It is noteworthy that one-third (21) of the species are represented by a single specimen each. While the number of new species is naturally much smaller than the *Blake* secured (for it must be remembered that the *Blake* was working over a much greater area of what was then almost virgin territory), the *Atlantis* has also brought back 20 of the *Blake's* novelties, usually in much larger series than the earlier collections contained. In the present collection, 44 genera are represented of which one is new and 8 have never been taken in the West Indies before. Special attention should be called to Astroceramus and Circeaster as Indo-Pacific genera now found to occur in West Indian seas. Almost as noteworthy is Tremaster hitherto known only from deep, cold water off New England and Psilaster also a genus of cold water or northern associations. The new genus Tessellaster is remarkable for its close structural relationship to a genus, Ceramaster, which its general facies scarcely suggests. On the whole, the *Atlantis* collection justifies the belief that our knowledge of the deep water sea-stars of the West Indian region is still far from complete, and that further collecting will throw more light on structural relationships, geographical distribution and the origins of this rich and interesting group.

In working over this exceptionally interesting collection of sea-stars, I have constantly fallen back on the extensive knowledge and sound judgment of the most eminent of authorities on the Asteroidea, Dr. Walter K. Fisher. His promptness and care in answering queries

and critically examining specimens have been of inestimable value and I herewith offer him my sincerest thanks. If I have had the temerity now and then to differ with him, it is probably more of a reflection on my judgment than on his.

Family Goniopectinidae

Goniopecten demonstrans

Perrier, 1881. Bull. M. C. Z., *9*, p. 24.

This is one of the *Blake's* novelties that has been taken by the *Atlantis* at 7 widely separated stations at both ends of Cuba and along the northern coast. All together, 15 specimens were secured at the following stations: 2990A, 2991, 2991A, 3314, 3366, 3459 and 3474, at depths of 415-625 fms. The smallest has R = 30 mm. and in the largest R = 177 mm. The proportion of R to r undergoes relatively little change during this growth, R = 4-4.5r in the entire series. In specimens with R 75 mm. or less there are conspicuous spines or spinelets on the supero-marginal plates, one to each plate, except on the distal part of the arm where they are wanting; these spinelets may be nearly or quite 2 mm. high and very acute. Similar spines but less conspicuous are present on many infero-marginal plates, even distally. But when R = 100, these spinelets have nearly all, and generally altogether, disappeared, tho they may reappear on infero-marginals on a regenerated part of the arm. In one specimen with R = 125 mm. a few of the superomarginal spines are still noticeable, and they are also evident on the distalmost infero-marginals.

Prionaster elegans

Verrill, 1899. Trans. Conn. Acad., *10*, p. 216.

This species was based on a single specimen taken by the *Albatross* in the Gulf of Mexico, in 142 fms. A specimen in the M. C. Z. was identified by Perrier as *Goniopecten demonstrans!* The locality where it was taken is unknown but it is possible it was secured by the *Blake*. The *Atlantis* is to be coongratulated for bringing back 36 specimens from no fewer than 24 stations (2960, 2961D, 2963B, 2982, 2982A, 2984, 3323, 3328, 3331, 3375, 3386, 3391, 3392, 3405, 3408, 3409, 3410, 3411, 3432, 3434, 3436, 3437, 3438 and 3478). This indicates that while Prionaster is found all around the island of Cuba, it is not abundant anywhere. At most stations only a single

specimen was taken and 4, all young, was the largest number in any one haul. In the Bahia de Cochinos, on the south coast, 8 specimens were taken in 150-320 fms. A single young specimen was found at the eastern end of the island, off Puerto Tanamo in 230 fms. The remaining specimens come from the Old Bahama and Nicholas Channels, in 210-265 fms. and from off Matanzas in 240 fms. Only 7 of the specimens are more than half grown and many are very small, the smallest having R = 8 mm. and r = 4; R thus = 2r whereas in large specimens R (155-165 mm.) = 8r (20 mm.) Even the very young specimens are identifiable by the characteristic marginal plates and fascioles. In two details of the growth changes this sea-star differs from Goniopecten; the proportion of r to R decreases greatly with growth, and the spinelets on the marginal plates persist even in the largest specimens. One of the half grown specimens has the upper surface more or less orange yellow bounded by the very pale yellow or nearly white superomarginals. In one of the largest specimens, the yellow tint is evident but it is buffy and not orange. All the other specimens are more completely bleached, but two of the largest have the distal portion of each ray violet-red. It is evident however that this conspicuous coloring is artificial, due to staining from other material with which they were packed.

Family Astropectinidae

Astropecten articulatus

Asterias articulata Say, 1825. Jour. Phila. Acad., *5*, p. 141.
Astropecten articulatus Müller & Troschel, 1842. Syst. Ast., p. 72.

A very good series of this Astropecten was taken along the northern coast of Cuba, between 78° and 81° 30′ W, chiefly in the Old Bahafa Channel, at depths of 150 to 260 fms., considerably deeper water than any in which it has previously been taken. There are 29 specimens in all, ranging from very young (R = 12 mm.) to adults of maximum size (R = 102 mm.) In the small ones R = 3r but in the adults, R = 6r; r and br are about equal.

On the whole the species characters are quite obvious but there is some interesting diversity. In many of the larger specimens there are erect spines, a millimeter or more in height, on the inner margin of some of the superomarginal plates in the interbrachial arc. A continuous series is very rarely developed but in the largest specimen such spinelets occur on the first 12-14 plates in each series; on the first one or two plates, 2 or even 3 such spinelets form a crowded

pair or group. Few of the specimens show any spinelets on the distal superomarginals but they do occur now and then, tho small and inconspicuous. In one specimen, spinelets occur irregularly even on the middle third of the ray, but in this specimen the spinelets are very irregularly developed. The presence or absence of pedicellariae on the adambulacral plates seems to be a matter of individual diversity, perhaps influenced by age. They may be present in quite young individuals (R = 30 mm.) tho they are not numerous at that stage. One adult with R = 90 mm. seems to lack them almost completely, but it is not very well preserved. In another individual of the same size, the pedicellariae are very conspicuous and numerous.

The stations where this species was taken are as follows; 2980A, 2980B, 2982B, 2982C, 2982D, 3386, 3389, 3392, 3396, 3400, 3417, 3420, 3422 and 3478.

Psilaster squameus[1] sp. nov.

(PLATE 2, FIG. 1)

Arms 5; R = 50 mm., r and br = 13-14 mm.; height of ray at base, 8 mm.; width of paxillar area at base of ray 7 mm., at middle of ray, hardly 3 mm.; actinal intermediate areas, about 8 mm. long (interradial line) by 8 mm. wide at distal margin. Similar to *cassiope* Sladen in general appearance and in the character of the large marginal plates, so that a detailed description is hardly necessary. The superomarginals encroach so much on the dorsal surface of the rays that the paxillar areas are very narrow and on the distal half of the arms they are quite insignificant, tho they persist to the terminal plate. The surface of all the marginals in both series is quite uniformly covered with flat, more or less circular squamiform granules; along the margins, forming the fascioles, the granules are minute and more or less spiniform; on the largest plates the squamiform granules are less crowded in the central area than marginally but there are no bare areas at all. There are no spinelets on the superomarginals but each inferomarginal plate on the basal half of the arm carries at its upper distal corner 2 or 3, slender, flat, appressed spines 1.5-2.5 mm. long; these disappear altogether distally while basally, in the interradial angle, similar and even larger spines occur along the lower distal margin of a few plates.

In the covering of the lower end of the inferomarginals and in the armature of the adambulacral plates, the West Indian specimens differ so much from the Cape Verde Islands' *cassiope*, that it would be unwise to refer them to that species. In *cassiope*, Sladen emphasizes the granule-like character of the covering of the marginal plates and

(1) *squameus* = *scaly*, in reference to the covering of the marginal plates.

says that only careful examination shows their squamiform shape; moreover his figure shows that on the inferomarginals they tend to be pointed. In *squameus*, the squamiform character is marked and they are not at all pointed but nearly circular. Moreover they are not so crowded as they seem to be in *cassiope*. According to Sladen the armature of the adambulacral plates consists of a furrow series of 7 or 8 "short, delicate, cylindrical, equal spinelets" and on the surface, "one or two longitudinal series of three or four equal spines, slightly shorter than the inner series", but the adds there is frequently "irregularity in the disposition of these spinelets" and the arrangement may be "difficult to formulate". His figure shows 4 longitudinal series of 4 spines each, all quite similar to the furrow series. Now, in the West Indian species, the furrow series consists of 8 or 9 very slender, flattened, blunt or somewhat truncate spines, the middle ones longest but the distal 2 or 3, the widest. On the surface of the plate, there is more irregularity in number and arrangement, but these spinelets are shorter and wider than the furrow spines and their tips may be flat and widened considerably. It is of course possible that a good series of specimens would show that these differences between *cassiope* and *squameus* are not constant but until such a series is available, the Cuban specimens had best be distinguished by a different name. They are in their present dry condition cream-color with the oral side more yellow and the paxillar area more gray or brownish.

Holotype M. C. Z. No. 3811, from *Atlantis* St. 2991A, in Nicholas Channel, off Bahia Santa Clara, northern coast of Santa Clara Province, in 475 fms. There are 2 paratypes, one with R = 60 mm., from St. 2991 only a few miles from where the holotype was taken, the other, with R = 56 mm., from St. 3443 which is also in Nicholas Channel but a little farther east, and in shallower water, 325 fms.

Verrill (1915) does not include Psilaster among West Indian sea-stars, nor are there any specimens in the M. C. Z. south of 38° in the western North Atlanic. Apparently *squameus* has a restricted range between the Bahamas and Cuba.

Plutonaster bifrons

Archaster bifrons Wyville Thomson, 1873. Depths of the Sea, p. 122.
Plutonaster bifrons Sladen, 1889. *Challenger* Ast., p. 84.

Altho there are 15 sea-stars, referable to this handsome species, all are young and so small, their identification cannot be assured.

None of them have a conspicuous spine on the actinal surface of the adambulacral plates, tho in other respects their spinulation is very much like the adults. The smallest individual has R only 15 mm. and only 2.5r. The largest has R = 37 mm. and r about 10. Excepting the smallest, which was taken at St. 2994, off Bahia Cardenas, Santa Clara Province, in 565-585 fms., all of the specimens were taken in very deep water (830-1015 fms.) off the northeastern coast of Oriente Province (Sts. 2975, 3359 and 3363).

Plutonaster intermedius

Goniopecten intermedius Perrier, 1881. Bull. M. C. Z., *9*, p. 25.
Plutonaster intermedius Perrier, 1894. *Travailleur* et *Talisman* Ech., p. 316.

A small, flat sea-star, with R = 23 mm. and r = 11, was taken by the *Atlantis* at St. 2994, off Bahia Cardenas, Santa Clara Province, in 565-585 fms. Comparison with a cotype of Perrier's *intermedius* shows it is without doubt a young individual of that species. It shows the scars of several healed injuries and the terminal portion of one ray is missing. The color is pure white. The species was not met with during the 1939 cruise.

Persephonaster pulcher

Archaster pulcher Perrier, 1881. Bull. M. C. Z., *9*, p. 26.

There is a small sea-star in the *Atlantis* collection from an unknown station which on comparison with the unique holotype of Perrier's species proves to be identical with it. In Fisher's (1911, p. 39) invaluable key to the genera of Astropectinidae, these specimens run down readily to the genus Persephonaster. While they are obviously immature, they may rest there until adults are found which prove that this genus is not their ultimate "place of resting".

The *Atlantis* specimen is somewhat larger than Perrier's, as R = 20 mm., r = 6 mm. and br = 6. The terminal plates on rays are very large and each carries 3 relatively big spines. The resemblance to specimens of *Psilaster patagiatus* of the same size is very marked but the paxillae have fewer and shorter spinelets, there seem to be no pedicellariae, the covering of the marginal plates is smoother and more uniform and the furrow series of 5-7 adambulacral spines are longer and more slender. Side by side the specimens of *pulcher* are easily distinguishable from young *patagiatus*.

Persephonaster echinulatus[1] sp. nov.

(Plate 3, fig. 2)

Arms 5; R = 25 mm.; r and br = 8; br, halfway to tip, 5 mm. The largest specimen which is not so well preserved and hence is not so suitable for a holotype, has R = 40 mm.; r and br = 10; br halfway to tip, 6 mm. In the smallest specimen R = 12 mm.; r and br are less than 4. Disk slightly elevated at center with a low but distinct proctal cone. Paxillae numerous, very low, with 4-7 relatively long and slender spinelets as their crown; here and there the paxillae are replaced by rather stout, fasciculate pedicellariae, with 3, or rarely 4, jaws. Madreporite of moderate size, about as far as its own diameter from the marginal plates. The paxillar area on each ray continues to the terminal plate with no sudden or disproportionate decrease in width. Superomarginal plates 16 or 17 on each side of ray; in the largest specimen there are 24. In the interbrachial arc they are longer than wide and higher than long, but they slowly become, at the arm-tip, wider than long and longer than high; they are covered with minute spinelets, which are rather sparsely distributed on the slightly convex, upper central part of plate but are very abundant around the margin; distally the spinules are fewer and more minute so that the last 2 or 3 plates are nearly bare; each plate on the basal part of arm carries a distinct tho small, erect spinelet near the inner distal corner of its upper end, but distally these spinelets gradually disappear. The inferomarginals are similar in form and appearance to those of the upper series but are a little larger; their spinulose covering is similar but each carries in addition, on the distal half, an oblique series of 2, 3 or 4 relatively long (2 mm. or more) slender, terete spines which overlie the following plate; distally these spines are smaller and ultimately disappear.

Actinal intermediate areas very small covered by a dozen or fifteen plates; there is a series of 4 or 5 between each oral plate and the marginals; smaller plates extend out between the adambulacrals and marginals, a single series of small, elongated ones reaching beyond the middle of the arm. All of the actinal plates carry numerous slender spinelets, similar to those on the inferomarginals but somewhat longer and stouter; they are not at all sacculate. Adambulacral plates rather long and narrow, excepting near mouth; first one is very short and wide, second is somewhat narrower and third is about as wide as long; adambulacral armature consists of a furrow series, commonly of 5 spines, the middle ones longest; on the basal plates, this series is angular with 2 spines on the furrow margin and 3 on the distal side; on the second plate the angle is less sharp and on the third it is scarcely noticeable; on succeeding plates, the furrow margin and series of spines make a simple curve. On the

(1) *echinulatus* = *set with small spines,* in reference to the character of the marginal plates.

surface of the plate are a few scattered and irregularly placed spinelets like those of the actinal plates. There are 2-4 fasciculate pedicellariae on each actinal area, but they are very simple, hardly more than groups of 3 or 4 spines. Oral plates relatively large and prominent, swollen along the interradial suture; beside this suture (on each plate) is a series of 8-10 spinelets, the distal ones very small, the proximal ones increasing in size to the terminal tooth on each plate, which is a millimeter long, flat, spatulate and rounded at tip; along the outer margin of each oral plate is a series of 7 or 8 small slender spinelets and above this is a second series of 5 similar spinelets. On each side of the jaw, below the level of the terminal teeth and the lateral spinelets, is a cluster of 5 crowded, blunt, flattened spinelets, the characteristic feature of Persephonaster. Color (dried) of paxillar area light grayish-brown; marginal plates and lower surface nearly white, the spines and spinelets more or less yellowish.

Holotype, M. C. Z. No. 3812, from St. 2989, in the Nicholas Channel, off Puerto Sagua Grande, Santa Clara Province, northern coast of Cuba, in 360 fms.

There is a good series of this species but the larger ones are in poor condition and it seems best to select one little more than half-grown for the type. Of the 24 specimens, 10 are clearly young, less than half grown, and only 4 are larger than the holotype. Most of the lot agree with the type in color but many are more completely bleached; those from St. 3485 are definitely gray rather than brown while 2 from St. 2987A are distinctly pink and suggest that the color of this sea-star in life may be some shade of red. Structurally the specimens show little diversity save in the number of pedicellariae and the number and length of the longer spines. The character of the paxillae and other details of spinulation distinguish the species easily from Koehler's species *humilis* from the Azores, nor does there seem to be any other species to which it is any more closely allied. To judge from the fact that this species was not taken by the *Blake*, it must have a restricted range or be very local in its distribution. This idea is confirmed by the fact that tho the *Atlantis* secured specimens in both 1938 and 1939, all of the material was taken between Matanzas and Caibarien, northern coast of Cuba, and chiefly in Nicholas Channel. The bathymetrical range is similarly restricted for all the specimens are from depths of 285-390 fms. It may further be noted that at only 2 stations were more than 2 specimens secured. The station numbers are 2987A, 2987C, 2987D, 2988, 2989, 3442, 3443, 3445, 3447, 3449, 3468 and 3485.

Persephonaster leptactis[1] sp. nov.

(Plate 3, fig. 1)

Arms 5; R = 36 mm.; r = 9 mm.; br = 8 mm. at base, 4 mm. halfway to tip. Disk somewhat wrinkled in the dry specimen, indicating that it was somewhat swollen in life; it is closely covered with small knob-like paxillae carrying 5-12 (seldom more) short, thick, prickly spinelets, about as long as the paxilla-knob is high, or somewhat longer; on the central part of the disk and along the median line of the rays, the paxillae (or the plates which bear them) are so crowded there are no papulae in those areas. The madreporite is small but tumid and distinct, rather more than its own diameter from the superomarginal plates. The paxillar area on each ray is very narrow, 2 mm. wide at a point halfway to tip and becoming less than a mm. wide distally; it is virtually non-existent between the terminal 4 or 5 pairs of superomarginal plates. There are 25 or 26 of these on each side of each ray; distally they are about as long as high and the width is scarcely more, but proximally they are higher than long and in the interbrachial arc the width is less than the length while the latter is less than half the height. The inferomarginals are very similar and match the upper series very closely but they are not so high in the interbrachial arc. Both series are closely covered with low, blunt, spiniform granules, rather sparsely distributed on the most convex portion of each plate and most crowded near the margins. There are no spines on the superomarginals but each inferomarginal carries near the distal margin, usually at or below the middle, 2 (rarely 3 or even 4) slender, somewhat flattened tapering spines 2 mm. (more or less) long, which lie diagonally across the upper part of the next distal plate; on the distal half of the arm these spines are greatly reduced in size.

Actinal intermediate areas very small, covered by about a dozen plates; there is a sereis of 4 between each oral plate and the marginals; smaller plates extend out to the third of fourth inferomarginal. All of the actinal plates carry short, cylindrical, blunt spines, not at all sacculate. Adambulacral plates rather long and narrow; there is a curved marginal series of half a dozen (5-7) spines, of which the middle ones are apparently longest, those at each end shortest; however as nearly all are more or less broken, this statement needs confirmation. On the actinal surface of the plates, there are scattered spines similar in size and form to those on the actinal plates, but owing to the condition of the specimen it is difficult to determine the normal number and arrangement; on some plates it is evident that there is (or was) a single isolated spine, larger than the others, but apparently this was not usually the case, for on most of the plates, no one spine is conspicuous. Oral plates relatively large and

(1) λεπτός = *slender* + ἀκτίς = *ray*, in reference to the slender rays.

conspicuous swollen along the interradial line; the plates are rubbed and the spines broken or missing but apparently each plate carried a series of marginal spines, similar to the adambulacrals, a parallel series of somewhat smaller spines above the margin and a third series of still smaller spines along the interradial suture. Each plate carries at the proximal tip a very large, wide, flattened spine, beside which, in the furrow, is the group of half a dozen pointed spinelets, which Fisher (1919, p. 110) considers one of the distinguishing features of Persephonaster. No pedicellariae have been detected. Color (dried) pale brown, the marginal plates more nearly white, increasingly so on the distal half of the arm.

Holotype, M. C. Z. No. 3813, from St. 2970, in the Windward Passage, south of Oriente Province, in 1600-1800 fms.

This unique sea-star is apparently not very nearly related to other members of the genus. In Fisher's (1919) key to the 9 Philippine species of Persephonaster, the Cuban specimen runs down to *tenuis,* but the arms are much more abruptly attenuate and the armature of the inferomarginal plates is obviously different. No West Indian or Atlantic species hitherto known approaches it very nearly.

Persephonaster spinulosus[1] sp. nov.

(PLATE 3, FIG. 3)

Arms 5; R = 73 mm.; r and br = 22 mm.; R = 3.3r. Very similar to *Psilaster patagiatus* Sladen (which is undoubtedly a Persephonaster) taken by the *Challenger* off the Cape Verde Islands. The rays are relatively shorter and wider and the superomarginal plates are somewhat less numerous; these plates occupy much more of the abactinal surface so that the paxillar area is just one-third of the basal arm-width instead of one-half as in *patagiatus.* The paxillae are quite normal with the spinelets erect or spreading; only here and there are any closed up as Sladen describes and figures them. I think this peculiar closed condition of the paxillae in the type of *patagiatus* is artificial, the result of unusual conditions when the specimen was preserved. The low tubercle-like spines, one on each plate, which Sladen describes as occurring "sometimes" on the superomarginals are very evident in the larger Weest Indian specimens; they are not shown in Sladen's figure. The presence of pedicellariae on the superomarginal plates is a very variable feature; in some specimens they are obvious and may be numerous, on the paxillae as well as on the marginal plates, but in the holotype and several others, they are difficult to find, if not actually quite

(1) *spinulosus* = *bearing small spines,* in reference to the small spines on the actinal plates.

wanting. The most important differences between the Cape Verde and the Cuban specimens are to be seen on the oral surface. Actinal intermediate areas in *spinulosus* are small and the actinal plates only extend to the eighth or ninth infero-marginal. The spinulation of the whole actinal surface is sparse and the separate plates are more or less readily distinguishable. On the actinal plates the spinules are short, slender and usually pointed, of somewhat unequal sizes; one is much larger than the others and may properly be called a spine; it is situated near the distal corner of the plate and lies flat, overlying the next plate; sometimes one or more of the spinules are enlarged to a lesser degree. These actinal spines seem to be quite wanting in *patagiatus*. The adambulacral armature in *spinulosus* consists of a furrow-series of 8 slender, somewhat flattened (laterally) spines, and an irregular, scattered group of 10-12 spinelets on the actinal face of the plate; the larger spinelets are long and very acute, but they are not so large as those of the furrow series. The oral plates are essentially as in *patagiatus* but the spinelets are apparently longer and more pointed.

The M. C. Z. has one of the *Princess Alice* specimens recorded by Koehler as *patagiatus*. It is the first one listed in Koehler's account of the species (1909, p. 62), from St. 553, in the Azores Islands, 1385 m. (769 fms.) and now bears the M. C. Z. cat. No. 2713. This specimen clearly is not identical with either the type of *patagiatus* or with the Cuban specimens, but at first sight more nearly resembles *Psilaster andromeda* to which Perrier, according to Koehler, has referred many specimens that the later writer considers *patagiatus*. In my judgment, this Azores specimen cannot be referred correctly to any one of the 3 species but represents an apparently as yet unnamed species of Persephonaster. As shown in Koehler's figures the superomarginal plates are very high, short, scarcely tumid and encroach but little on the upper surface of the ray. Superficially the resemblance to *andromeda* is certainly greater than to either *patagiatus* or *spinulosus*.

The holotype of *spinulosus* is M. C. Z. No. 3814. It was taken at *Atlantis* St. 3457, in Nicholas Channel, off Bahia de Santa Clara, in 550 fms. A tiny sea-star from the same station, with R = 3.5 mm. is apparently a young individual of the same species tho it is of course too young for positive identification. It has but 3 superomarginals on each side of the arm and each arm terminates in a relatively huge plate that carries 3 big, acute, divergent spines nearly a millimeter long. From St. 3313, northwest of Cabo San Antonio, Pinar del Rio Province, 500 fms., there are 5 specimens, an adult with R = 58 mm. and 2 smaller ones, and 2 young with R = 28 and

15 mm. respectively; the smaller has 3 divergent, blunt spines, scarcely a millimeter long, on the terminal plate; in the larger, these spines are in evidence on 2 of the 4 terminal plates present. A small sea-star (R = 12 mm.) from St. 3370, northeast of Puerto Tanamo, Oriente Province, 450 fms., has received such rough treatment that the terminal-plate spines are gone, but there is little doubt it belongs to this species. A specimen of Persephonaster, with R = 30 mm. from Bahia de Corrientes, Pinar del Rio Province, 615 fms., is best referred to this species, tho it is not typical; it is notable for its many pedicellariae. There are 3 more specimens of *spinulosus* at hand; one an adult from St. 3367, northwest of Puerto Cayo Moa, Oriente Province, 640 fms., with R = 63 mm. but br only 18; and 2 from Nicholas Channel, off Bahia de Santa Clara, 475-555 fms. One of these, from St. 2991A, has R = 45 mm.; the terminal plate is present on only one ray but it still shows the bases of the 3 spines, so conspicuous in youth. The other, from St. 2992A, has R = 63 mm. and is even stockier than the holotype, for r and br=21 mm., so that R=only 3r. The superomarginal tubercular spines are particularly noticeable and 2 or even 3 may occur on one plate, but in such cases, one is distinctly larger than the others. The spines on the actinal intermediate areas are particularly well developed. Of the 12 specimens all but one are, in their dry condition, more or less nearly cream color; the small specimen from 2983 is definitely light brown with a reddish cast.

Family Luidiidae

Luidia barbadensis

Perrier, 1881. Bull. M. C. Z., *9*, p. 29.

The *Atlantis* did not meet with any Luidias in 1938 but in 1939, this species, one of the *Blake's* discoveries, was taken at five stations in the Old Bahama Channel in 180-235 fms. Curiously enough however no really adult specimens were collected. All but one of the 6 taken are very small, with R = 12-25 mm., and all have 6 arms. The largest has every arm more or less damaged; the only one that is complete has a basal portion of 25 mm. and a regenerated terminal part 35 mm. long. The color of this specimen is faintly reddish but all of the others are cream-white. The species is remarkable for its slender arms; the specimen with R = 25 mm. has br only a trifle more than 3 mm. The stations where this Luidia was taken are 3386, 3389, 3399, 3401 and 3413.

Family Benthopectinidae

Benthopecten spinosus

Verrill, 1884. Amer. Jour. Sci. (3), *28*, p. 218.

The *Atlantis* met with this deep-water sea-star but once in 1938 (St. 2975, off Punta Lucrecia, Oriente Province, 1015 fms.) and only twice in 1939 (St. 3355, off Bahia de Guantanamo, Oriente Province, 1070 fms. and St. 3362, northwest of Baracoa, Oriente Province, 1020 fms.) All of the 8 specimens are small and immature and in more or less badly damaged condition. In the largest R was about 50 mm. apparently, while in the smallest it is but 16 mm.

Cheiraster coronatus

Archaster coronatus Perrier, 1884. *Blake* Stell., p. 262.
Cheiraster coronatus Perrier, 1894. *Travailleur* et *Talisman* Ech., p. 271.

The series of Cheirasters taken by the *Atlantis* are of very great value in making clear the limits of two of the perplexing species. At first Perrier failed to distinguish them from each other but called them both *Archaster mirabilis*. Later he distinguished *coronatus* as something different but failed to make clear just where the difference lies. Consequently Verrill (1915, p. 127) was led to conclude there is no valid, constant distinction and he listed *coronatus* as a subspecies of *mirabilis*. As a matter of fact adult specimens of *coronatus* are readily distinguished from *mirabilis* and even when R is no more than 20 mm., identification is usually easy. The most obvious difference is in the paxillae. In *mirabilis*, the paxillae are very low and are closely covered by a group of minute spiniform granules, none of which are enlarged or lengthened into spinules; the paxillar field is thus relatively flat and smooth. In *coronatus*, on the other hand, the paxillae are more convex and carry fewer and more unequal granules, one (or sometimes more) of which is elongated into a spinule. These spinules show considerable diversity in size and abundance; in some specimens they are abundant and more or less conspicuous but often they are small and infrequent. In very young specimens of both species, the paxillar granules tend to be spiniform, of unequal length and rather sparsely distributed. Besides this difference in the paxillae, a more obvious feature commonly separates *mirabilis* from its congener, and that is the presence at the center of the disk of a cluster of 3-10 relatively conspicuous,

acute spines, 3-8 mm. long. Spines 3 or 4 mm. long may occur on the disk paxillae in *coronatus* but they never form a conspicuous isolated group. In both species there is a tendency for the prominent spines on the basal superomarginal plates, particularly the fourth, to become conspicuously enlarged, but in *coronatus* they are rarely as long and stout as in *mirabilis*. In the *Atlantis* material, the biggest fourth superomarginal spines of any *coronatus* are scarcely 5 mm. long but in adult *mirabilis* they are 10-12 mm. long and may be more than 1 mm. in diameter at base.

When these three sets of characters are taken into account, it is easy to distinguish Perrier's two species from each other, except in the case of some very young individual where R is less than 20 mm. Apparently the two species rarely occur together for while *coronatus* was taken at 34 stations at only 2 of these were specimens of *mirabilis* secured; in both these cases, the specimens of coronatus are very young and it is not impossible that they did not originate at the station whose number they bear.

Altogether there are 72 specimens of *coronatus* at hand but only 7 or 8 of these are adult; they range in length of R from 40 to 65 mm. The largest specimen has all the arms broken but R must have been not less than 80 mm. for in adults R = 6.5r and in this specimen r = 12 mm. and more. The small specimens have R = 7.5-30 mm.; R = 3-5r. This material was secured for the most part on the northern coast of Cuba in the Old Bahama Channel, the Nicholas Channel or off Matanzas, in 145-605 fms., but indubitable specimens were taken northwest of Cabo San Antonio, 550 fms.; in Bahia de Cochinos, on the southern coast of Santa Clara Province, 270 fms.; off Guantanamo, Oriente Province, 1070 fms.; and on the northern coast of Oriente, off Puerto Tanamo, 450 fms., and off Puerto Cayo Moa, 830 fms. The station numbers are 2960, 2981, 2982, 2982A, 2982D, 2982E, 2990A, 2990B, 2991, 2991A, 2995, 2999, 3313, 3355, 3363, 3370, 3386, 3387, 3389, 3391, 3392, 3400, 3401, 3406, 3408, 3410, 3411, 3412, 3451, 3459, 3465, 3478, 3479 and 3483.

Cheiraster mirabilis

Archaster mirabilis Perrier, 1881, Bull. M. C. Z., *9*, p. 27.
Cheiraster mirabilis Perrier, 1894. *Travailleur* et *Talisman* Ech., p. 276.

This species is represented in the present collection by 46 specimens taken at 16 stations, all but one of which were between Caibarien and Matanzas, on the northern coast of Cuba, south of Cay

Sal Bank, in 260-500 fms. The one exception was in Bahia de Corrientes, southern coast of Pinar del Rio Province, western Cuba, in 350 fms., where 2 small but typical specimens were taken. The station numbers are 2987, 2987A, 2987C, 2987D, 3315, 3437, 3438, 3439, 3442, 3443, 3444, 3445, 3447, 3449, 3459 and 3483.

The characters by which *mirabilis* is to be distinguished from *coronatus* have been set forth above under the account of the latter species. The specimens at hand are mostly small but several have R = 70-80 mm. and one has R nearly or quite 125 mm. with r = 15 mm.; in the adult therefore R = 8r at least. This is in accordance with the general impression that *mirabilis* has somewhat narrower arms and smaller disk than *coronatus*.

Luidiaster enoplus

Cheiraster enoplus Verrill, 1915. Bull. Univ. Iowa, Lab. Nat. Hist., 7, p. 135.

This species was described from a single specimen, with R = 185 mm., taken by the *Albatross,* south of eastern Cuba, in 400 fms. So far as I know no additional material has been recorded. In the *Atlantis* collection, there is a specimen, in very good condition, with R = about 120 mm. It was taken in 400 fms. off Bahia de Cochinos, southern coast of Santa Clara Province, St. 2963F. Altho only two-thirds as large as the type, this specimen answers well to Verrill's description. I have placed it in Luidiaster, solely because of the presence of 2 large spines on the actinal surface of the adambulacral plates. Verrill says frankly that he attaches "no generic importance" to that character but I confess I do not see any other external character by which the genus Luidiaster can be recognized. The type of the genus is *L. hirsutus* Studer and specimens of this species from South Africa are at hand for comparison with the West Indian Cheirasters and Luidiasters. Mortensen (1933, p. 231) says that in some specimens of *hirsutus* there are 3 spines, in others 2 and in some only a single spine on the actinal face of the adambulacral plates. Unfortunately he makes no reference to size or age. The material I have examined leads me to believe that this diversity is due to age, and mature specimens (say with R = 50 mm. or more) will always have 2 and usually 3 such spines on the plates near the middle of the arm; both proximally and distally there is generally a reduction in the number, so that there is only a single spine on the plates in those areas. Accepting this armature of the adambu-

lacrals as the distinguishing mark of Luidiaster I am including Verrill's fine species therein. But I am frank to confess that a careful revisión of the Benthopectinidae is needed and I suspect that Pontaster, Cheiraster, Luidiaster and perhaps Pectinaster need to be "shuffled and dealt again". The distribution of pedicellariae seems to be a particularly unreliable character, and alterations in spinulation due to maturity and perhaps to senescence need to be carefully considered.

Luidiaster mixtus

Pectinaster mixtus Verrill, 1915. Bull. Univ. Iowa, Lab. Nat. Hist., 7, p. 135.

Here again I am placing a species described by Verrill, in the genus Luidiaster on the strength of its adambulacral armature. There are very commonly 3 spines on the actinal surface of the adambulacral plates in adult specimens. Unfortunately Verrill selected for his type an individual with R only 26 mm. He admits it is probably immature and the *Atlantis* collection demonstrates that it was not even half-grown, for specimens wtih R nearly or quite 60 mm. are not rare. Nevertheless I have no doubt that this Cuban material really belongs to Verrill's species, and comparison with *L. hirsutus* Studer satisfies me that the two are congeneric tho the papularium in the South African species is larger and has more and bigger papulae than in the Cuban. There is however no little diversity in this respect in the *Atlantis* material which consists of 60 specimens ranging from R = 7 to 65 mm. In the adults R = rather more than 5r or br. The spinulation of the marginal, actinal, adambulacral and oral plates in the large individuals is very striking, but the pectinate pedicellariae are not very abundant and in some specimens are wholly wanting; showing that they are not reliable as a generic indicator.

The *Atlantis* material, except for 2 specimens, was taken along the northern coast of Cuba between 78° and 81° 30′ W., chiefly in the Old Bahama Channel, in depths of 195-265 fms. The exceptions are a very typical adult (tho it lacks pedicellariae) from Bahia de Cochinos, on the southern coast of Santa Clara Province, in 155-190 fms., and a half grown individual from off Baracoa, Oriente Province, in 1000 fms. This specimen has certain peculiarities of spinulation perhaps associated with the great depth at which it was

taken. The 15 stations, at which *mixtus* occurred, are 2963A, 2981B, 2981C, 2982C, 2984, 3359, 3388, 3392, 3393, 3413, 3423, 3427, 3438, 3480 and 3482.

Luidiaster dubius[1] sp. nov.

(Plate 2, fig. 2)

Arms 5; R = 60 mm.; r and br = 14 mm. Very similar to *mixtus* but disk larger and arms wider at base; paxillae higher and more sparsely spinulated, very similar to those of *Cheiraster coronatus*. Marginal plates and armature much as in *mixtus* but the spinules are longer and less numerous and the spines are much stouter. Actinal intermediate areas much larger than in any other Benthopectinid in the *Atlantis* collection but very similar to those of *Luidiaster hirsutus;* there are about 30 plates on each area, arranged in 4 series, which extend to the third inferomarginal and the fifth adambulacral. There are no pedicellariae. Armature of the adambulacral plates much as in *mixtus* but usually there is only a single large spine on the actinal surface; distally however there are often 2 and sometimes 3, and proximally there is a tendency to 2 spines on many plates, tho one is always much the larger. Unlike all the other Benthopectinids at hand, this individual has a dintinct reddish color, especially orally (excepting the distal part of each arm).

Holotype, M. C. Z. No. 3815, from St. 3326, Bahia de Cochinos, south side of Santa Clara Province, 265 fms.

This peculiar specimen has led at different times to several different conclusions. Taken by itself it might be considered a Pontaster or a Cheiraster but it is so similar to *Luidiaster mixtus* it seems as tho it must be at least congeneric therewith. Indeed I have been tempted to regard it as an aberrant representative of that species. Again I have been tempted to resort to that commonly used catch-all for puzzling specimens and label it as a hybrid of *mixtus* and some related form, shall we say *Cheiraster coronatus?* But on the whole it seems wisest to give it a distinctive name and "await more material".

Family Odontasteridae

Odontaster hispidus

Verrill, 1880. Amer. Jour. Sci. (3), *20*, p. 402.

At St. 2993, on her first cruise, the *Atlantis* took a single small Odontaster, which may properly be referred to this species, tho it

(1) *dubius* = *doubtful,* as there is but one specimen and it may be a hybrid.

has been so badly rubbed during its long upward journey in the dredge (580 fms.), it has lost most of the spinules and slender spines which the name suggests. It is also damaged and 2 arms are broken off at the base, but it is nevertheless of interest and value for the *Blake* took no specimens of Odontaster and the *Atlantis* did not meet with the genus again. Obviously this is not a West Indian sea-star but is a wanderer from the north having been repeatedly taken along the continental shelf from Marthas Vineyard to Florida, in 43-480 fms. The *Atlantis* specimen is young, with R only 18 mm. It was secured northwest of Bahia de Santa Clara, directly south of Florida, and this would seem to be the extreme southern limit of the species' range. The size and condition of this specimen does not permit of positive assurance that it is not either *setosus* or *robustus* Verrill. Those species are not as yet represented in the M. C. Z. collection.

Family Goniasteridae

Pseudarchaster concinnus

Verrill, 1894. Proc. U. S. Nat. Mus., *17*, p. 250.

There are 5 very fine specimens of this handsome sea-star, but none is as large as Verrill's largest. The *Atlantis* specimens have R = 45-73 mm. with r about one-third as much. The species is obviously not abundant in the West Indies as it was not met with in 1938. Verrill's specimens came from very deep water (1188-1791 fathoms.) off Georges Bank, and there are specimens in the M. C. Z. collection from off Nantucket, 1100-1230 fms. The occurrence in much shallower water near Cuba is therefore quite unexpected but I find no noticeable differences between the Nantucket specimens and those in the *Atlantis collection*. One of the latter (from St. 3357) with R = 71 mm., is from much deeper water (857 fms.) than the other 3 and from much further south, lat. 20° 39′, north of Baracoa, Oriente Province. There are slight differences in spinulation between this specimen and the others, the granules on the marginal plates; and on the paxillae, being less crowded and the spinelets on the actinal surface somewhat fewer and more slender. This condition can hardly be attributed to the greater depth however for specimens from still greater depths south of Nantucket are like the Cuban specimens from Sts. 3449, 3450 and 3451, south of Cay Sal Bank,

in 390-405 ffs. It is worth noting that this is the same general region in which another northern species, *Odontaster hispidus,* was taken.

Pseudarchaster parelii

Astropecten parelii Düben and Koren, 1846. Kongl. Svensk. Vet. Akad. Handl. 1844, p. 247.
Pseudarchaster parelii Fisher, 1911. Bull. 76 U. S. Nat. Mus., p. 180.

It is interesting to find that this widespread circumpolar sea-star extends its range as far south as Cuba. The *Atlantis* only met with it once in 1938 but the following year found it repeatedly. There are 41 specimens at hand, but oddly enough only one can be considered adult (R = 46 mm.) and nearly all are very young with R = 18 mm. or less; the smallest has R = 7 mm. Excepting 10 very young individuals from Bahia de Cochinos, southern coast of Santa Clara, all of the specimens came from the northern coast of western Cuba, and chiefly from the Old Bahama Channel, in 145-475 fms. The adult specimen is from the greatest depth (475 fms.); all the others were living in 145-260 fms. The station numbers are 2991, 2999, 3303, 3320, 3333, 3335, 3336, 3386, 3390, 3391, 3398, 3399, 3400, 3403, 3406, 3409, 3413, 3414, 3416, 3417, 3420, 3421, 3423, 3428 and 3480. The notable absence of adult specimens in this series leads me to quote a paragraph from a letter from Austin Hobart Clark, the world authority on crinoids, whose duties at the National Museum, have led him to examine many collections of echinoderms from the West Indies: "A curious feature about the Caribbean is the enormous percentage of young individuals in all the collections. Apparently life is very strenuous and most of the young die before they can grow up."

Paragonaster grandis[1] sp. nov.

(Plate 4, fig. 1)

Arms 5; R = 80 mm.; r and br = 27; halfway from center of disk to tip of arm, br = 14 mm.; thickness of disk in interbrachial arc, 10 mm. Paxillar area of disk very flat, about 40 mm. across, the sides of the pentagon about 30 mm. long. Paxillae stout, only a little convex, rather small and closely crowded at the center of the disk and near the interradial margins; on the radial areas of the disk

(1) *grandis = pre-eminent,* in reference to its large size and broad disk.

the tops are more or less circular, 1.5 mm. across and covered by 8-15 rounded flattened granules, surrounded by a circle of 10-20 rather inconspicuous, short, slender spinelets; where crowded together these large paxillae tend to become hexagonal. Beyond the eighth superomarginal, there is only a single series of plates, extending to the terminal plate; at first these which are not paxilliform, are oblong, much wider than long, but they soon become squarish and distally they are very small and longer than wide; when squarish, one or the other of the lateral sides is apt to be convex and thus the plate tends to be rounded pentagonal. Madreporite very small, hardly as large as the paxillae which surround it, about 8 mm. from the center of disk.

Superomarginal plates, 31 on each side, much wider than long, more or less nearly horizontal and encroaching much on the upper surface of disk and arms; those in the interbrachial arc are 8 mm. wide, but scarcely 2 mm. long at the inner end and less than that at the outer; the eighth plate is 6.5 mm. wide and 2.75 mm. long; the twentieth plate is 3 mm. wide by 2 mm. long. The superomarginals bear no spines or spinelets but are rather uniformly covered with flat-topped polygonal granules; along the lateral margins, these become much smaller and almost spiniform. Terminal plate relatively large, rounded hexagonal and somewhat swollen, apparently bare or with very few granules. Inferomarginals corresponding in number, position and size very closely with the upper series but rather less horizontal. They are covered with short, thick, ovate, pointed scales, more or less overlapping and directed towards the arm-margin; along the margins of adjoining plates they are minute and spinule-like. On each plate, more or less near the midline and most noticeable adorally, are 5-8 enlarged scales or small spines, the largest 1.5 mm. long or more; these show no regular arrangement and intergrade with the ovate scales but they are a marked feature of the inferomarginal armature.

Actinal intermediate areas large, covered by 50-60 plates, the largest of which adjoin the adambulacrals and extend out to the eighth or ninth inferomarginal. They are rather sparsely covered by spines and spinelets as are the lower marginal plates, but the spinelets are stouter, less flattened and much more acute than the thick scales of the marginal plates. Adambulacral plates with a marginal series of 7 or 8 blunt spines, the middle pair longest and straightest, the first and last shortest and slightly curved; along each lateral (proximal and distal) margin are 4 or 5 much smaller acute spines and the surface of the plate carries 8 or 10 spines and spinelets quite irregularly arranged, 2 or 3 of which are the largest spines on the plate; the largest spines are quite acute. No pedicellariae have been noted anywhere. Oral plates large and carrying so many spines that it is very difficult to determine their actual arrangement but by comparison with the paratype which has the mouth less tightly closed, it is possible to determine the approximate number of the spines and their probable arrangement. At the apex of the combined pair of oral plates there is a stout spine, 2 mm. long

with a compressed, enlarged rounded tip; on some of the jaws this seems to be at the apex of one oral plate and mated with a similar but smaller spine on its fellow. But in the paratype, on one jaw, this enlarged spine is clearly unpaired at the apex of the two plates. Extending backward along the free margin of each of these plates is a series of about 12 somewhat similar but smaller spines, blunt and somewhat compressed. Along the sutural margin of each plate is a series of 15 or 16 spines, the proximal ones large and blunt but distally they become small and sharp. On the convex surface of the plate, between these two series are 8-10 spines and spinelets of varied size and sharpness, but proximally all the spines on the oral plates tend to be large and blunt, distally they are small and acute. Color (dried) light wood-brown, the paxillar area with a slightly reddish cast, the marginal plates and actinal surface with a yellowish tint. The paratype is much lighter, a pale yellowish brown.

Holotype, M. C. Z. No. 3816, from Station 3000, off Bahia Matanzas, Cuba, 170-255 fms. The single paratype, which is slightly smaller but otherwise very similar, was taken at St. 3439, off Caibarien, Santa Clara Province, in 295 fms.

This fine sea-star resembles *Pseudarchaster concinnus* so much, not merely in general form and proportions but in the paxillae and the armature of the marginal, actinal and even the adambulacral plates that it was at first supposed to be simply a peculiar adult stage of that species but the complete absence of pedicellariae and the characteristic arrangement of the dorsal plates on the arms have compelled recognition of the fact that it is a Paragonaster and not a Pseudarchaster at all.

Mediaster pedicellaris

Goniodiscus pedicellaris Perrier, 1881. Bull. M. C. Z., *9*, p. 23.
Mediaster (?) *pedicellaris* Verrill, 1899. Trans. Conn. Acad., *10*, p. 182.

The rediscovery of this species by the *Atlantis* is of great interest because, altho Verrill states, both in 1899 and in 1915, that the *Albatross* has "taken" this species "in the West Indies", and such specimens may exist in either New Haven or Washington, the only recorded specimens are those in the M. C. Z. taken by the *Blake*. One of these is the holotype, no 470, used exclusively in the original description, and later (1884) figured in the final *Blake* report. Verrill has briefly redescribed this specimen twice (1899, 1915) and put it in the genus Mediaster, tho doubtfully, as he did not cut it open owing to the "lack of duplicate specimens". The other speci-

men in the M. C. Z. is the very small one with R = 17 (Perrier, 1894, p. 246, says "32 mm. d'envergure") taken at *Blake* St. 219, off St. Lucia, 157 fms. On p. 245, Perrier says there were "2 exemplaires" from this station, but this is evidently a slip for there is no second specimen in the M. C. Z., and on p. 247, he says "L'individu de Sainte-Lucie est de taille plus petite encore". The French writer refers in the preceding paragraph to "deux individus de Saint-Vincente" from *Blake* St. 224 but there are no such specimens in the M. C. Z. and it would seem from his comments that they were very doubtfully *pedicellaris*.

The *Atlantis* specimens are intermediate in size, and in their spinulation and general appearance admirable connecting links, between the 2 *Blake* specimens. The smallest was taken at the first station (3302) occupied by the *Atlantis* in 1939, off Playa Baracoa, Havana Province, 230 fms. It has R = 25 mm.; r = 7, and 6 pairs of superomarginal plates are in contact distally; in the little St. Lucia specimen at least 8 pairs are in contact. The *Atlantis* specimen is beautifully preserved and is bright brownish-yellow in color. A few days later in the Bahia de Cochinos, southern side of Santa Clara Province, at St. 3326, in 265 fms., a specimen, with R = 32 mm. and r = 11, the color a dingy brownish-white (now that it is dry), was taken. It has 5 or 6 pairs of superomarginals in contact on the rays. The third and largest of the *Atlantis* specimens was taken during the 1938 cruise at St. 2981B, in the Old Bahama Channel, off Punta Alegre, Camaguey Province, in 195-225 fms. It has R = 48 and r = 15 mm. and the 5 or 6 distalmost superomarginals are in contact. It is (dry) very pale brownish-yellow and in form and proportions resembles Perrier's type. The latter is however dingy white or pale gray in color. The resemblance of small specimens of this Mediaster to specimens of *Rosaster alexandri* is very striking as there is great similarity in the paxillar spinelets and in the adambulacral armature. But in Rosaster the superomarginals are united for nearly the entire length of the free ray regardless of agee while in Mediaster only the distal superomarginals are actually united along the radial line. Thus in Mediaster with R = 17 mm. r = 6, the paxillar plates extend out 10 mm. on the ray, while in Rosaster of the same size the paxillar plates only extend out 7 mm. Or, in other words, the paxillar area in Rosaster is very nearly a perfect pentagon tho the sides may be concave, but in Mediaster the paxillar area is pentaradiate, following the shape of the animal as a whole.

Of course the larger the specimen the more marked is this difference. A less striking difference may be seen in the covering of the superomarginals; in Mediaster it is made up of sharp, stout spinules, while in Rosaster it is composed of more rounded or at least, blunter granules.

Examination of the internal anatomy of the largest *Atlantis* specimen leaves no room for doubt that this species was rightly placed in Mediaster by Verrill. The abactinal plates are connected by independent internal radiating ossicles and superambulacral plates are definitely present.

TESSELLASTER(1) gen. nov.

A genus of Goniasteridae, related to Ceramaster as shown by the absence of internal radiating ossicles connecting the abactinal plates of the papular areas, the absence of superambulacral plates and of thin, serrate carinae on the inner face of the ambulacrals, and the presence of interradial gonads (not serial as in Mediaster); but differing in the greatly elongated radii, with numerous superomarginals, of which the distal 10-18 pairs are in contact in the midradial line. The disk is somewhat elevated or swollen, not flat, and there are apparently no pedicellariae.

Genotype: *Tessellaster notabilis* sp. nov.

Altho this sea-star has certain superficial resemblances to Rosaster and Nymphaster, the internal anatomy indicates that it is really more nearly related to Ceramaster, in spite of the striking difference in form. Dr. Fisher, who has kindly given me the benefit of his critical examination of this interesting new sea-star, says in his letter—whether the long attenuate rays with superomarginals in contact medially "alone justifies a new genus is questionable, judging by the behavior of Rosaster". But Rosaster even when very small (R = 4 mm.) is distinctly stellate with R very nearly = 2 r while the smallest and least pentagonal Ceramaster at hand has R only 1.5r. Moreover Ceramaster so seldom has more than 2 pairs of supero-marginals in contact medially, it seems to me a pity to extend the limits of such a homogeneous group to include so divergent a species as this new West Indian form.

(1) *Tessella* = diminutive of tessera, a small unit of mozaic work + *aster*, a common ending for genera of sea-stars; in reference to the appearance of the dorsal surface.

Tessellaster notabilis[1] sp. nov.

(Plate 5, fig. 1)

Arms 5; R = 95 mm.; r = 28; R = 3.8r; br at sixth superomarginal 12 mm.; R = 8 br. Superomarginals 30-32, beyond the 13th or 14th, closely in contact medially. At first they are wider than long and only slightly convex but distally they become more nearly square in outline, decidedly block-like and strongly convex. Distally they carry no granules whatever but soon minute marginal granules are to be seen, at first along the sides of the ray and then above in the median line, and basally each plate is surrounded on all four sides by a crowded but single series of nearly spherical granules. Irregular pits occur here and there on the surface of the plates but many of these are apparently artificial injuries; on a few plates however there are small more or less circular pits with a single granule at the center; occasionally 2, or even more granules occur and on some of the plates, forming the margin of the disk, irregular patches of granules are found and the lower end of these disk marginals is more or less completely granulated. Terminal plate rounded pentagonal, wider than long, somewhat swollen, larger than the adjoining superomarginals, smooth. Abactinal plates numerous and crowded, largest and most markedly tabulate on the somewhat swollen, radial, papular areas; here they are more or less hexagonal, but in the interradial areas, distally on the rays and at the center of the disk, they are pentagonal, square, oblong or even triangular. Each plate is closely covered with spherical granules, .15-.25 mm. in diameter; the marginal granules are angular as tho compressed by the granules of adjoining plates. There are no internal connecting ossicles. There is a large papular pore at each angle of the plate. On the rays the plates rapidly lose their tabulate, hexagonal form and become flat and oblong and soon form a single series, extending but little beyond the middle of the arm. On many of these radial plates there are small central areas without granules

Actinal surface very flat with the actinal intermediate plates rather large, irregularly pentagonal or tetragonal, and closely covered with slightly flattened spherical granules similar to those of the dorsal surface They extend out along the ray to the 15th or 16th inferomarginal. Inferomarginal plates correspond in number, size and form very closely with the supero-marginals but beyond the seventh or eighth, they are no longer directly matched with them but alternate regularly to the very arm tip. Within the disk they are more or less covered with granules, rarely if ever completely so in the holotype, but in the paratype 4-8 plates in each interradius are wholly granulated. Near the tip of the arm they become wholly bare tho the marginal granules persist to the last 3 or 4 plates.

(1) *notabilis* = *notable*, of obvious significance.

Adambulacral plates, longer than wide basally and out to the twenty-fifth (or thereabouts) when they become wider than long, but at the very tip of the arm the length and breadth are very nearly equal. Their armature consists of a furrow series of 8 or 9, more or less compressed spines, with rounded tips, and an irregular group of 12-20 coarse granules on the actinal surface of the plate; these granules are much larger than those on the actinal plates, so that they contrast markedly with them; they are arranged more or less imperfectly in two series parallel to the furrow. Oral plates similar to the adambulacrals, not at all swollen but quite flat. They have a marginal series of 8 or 9 heavy more or less prismatic spines, of which the distalmost is just like the adjoining adambulacral furrow-spines, while the more proximal are increasingly stouter and the one at the tip of the jaw is much the biggest spine on the animal. The surface of each plate is very well covered by about 20 granules and small prismatic tubercles. No pedicellariae have been detected anywhere on either holotype or paratype. Both specimens in their dry condition are light brown, becoming lighter on the actinal surface. The paratype is much lighter on the marginal plates and at the arm tips but this is hardly true of the holotype.

Holotype: M. C. Z. No. 3817, from St. 3388, in the Old Bahama Channel, off western end of Cayo Romano, Camaguey Province, 255 fms. The single paratype, a little smaller than the one described, is from the same region, St. 2981, Old Bahama Channel, off Punta Alegre, Camaguey Province, 225 fms. In the stomach of the paratype was a solitary coral, *Bathyactis symmetrica* (Pourtalès), 8 mm. in diameter.

This is surely one of the most interesting and striking of the echinoderms taken by the *Atlantis*. Its long arms suggest Nymphaster but the very different abactinal plates and its internal characters are convincing evidence that it has no close relationship with that genus. The gradually tapered, somewhat rounded arms give it a very different facies from either Rosaster or Mediaster, but it resembles still less any of the other West Indian Goniasteridae. It is somewhat surprising that the internal characters suggest Ceramaster as probably its nearest relative.

Ceramaster grenadensis

Pentagonaster grenadensis Perrier, 1881, Bull. M. C. Z., *9*, p. 19.
Tosia (Ceramaster) grenadensis Verrill, 1899. Trans. Conn. Acad. *10*, p. 162.

This species seems to have been known hitherto only from the holotype (M. C. Z. No. 416), taken by the *Blake* off Grenada in

576 fms. The *Atlantis* has met with it frequently in Cuban waters, having taken 13 specimens along the northern coast between Baracoa, Oriente, and Cabo San Antonio, Pinar del Rio, in depths of 315-1000 fms. (Sts. 2987D, 2988, 2992, 2995, 3313, 3359, 3363, 3377, 3449, 3450 and 3474). The only adult specimen (R = 29 mm.) is from off Bahia Cardenas, Matanzas, 370-605 fms.; it has distinctly concave sides (r = 18 mm.), somewhat more so than the holotype in which R = 26 mm., r = 18. The smallest specimen is from the greatest depth (1000 fms.) It has R = 9 mm., r = 7; there are 10 superomarginal plates on each side, but those adjoining the terminal plates are very small. There are very few granules on the upper surface, as they are pretty well confined to marginal series on the abactinal plates and along the inner margin of the superomarginals. Along the sides of the pentagon, where upper and lower marginals are in contact, granules are abundant, particularly on the inferomarginals which also have a single series along each lateral margin and a double series along the actinal margin. The actinal and adambulacral plates are granulated much as in the adults, only granules and spines are not so numerous and hence the plates are more sharply defined. A very similar but slightly larger specimen (R = 12.5 mm., r = 8.5) was taken in 830 fms. A specimen from St. 3450 is of somewhat unusual appearance as the disk is markedly convex and 3 pairs of superomarginals on each ray are fully in contact. One of 2 specimens from Bahia Cardenas, 490 fms., is a typical small *grenadensis* but the other is conspicuously different and may represent a different species but for the present it seems better to consider it an aberrant *grenadensis*. It is nearly pentagonal, R = 20 mm. and r = 17. The granulation is coarser everywhere and the oral and adambulacral spines are much heavier. This is particularly noticeable in the furrow series, for one of the best specific characters in *grenadensis* is the slenderness of the spines in the furrow series as compared with the spinelets and granules of the surface of the plates.

Nymphaster arenatus

Pentagonaster arenatus Perrier, 1881, Bull. M. C. Z., *9*, p. 21.
Nymphaster arenatus Sladen, 1889. *Challenger* Ast., p. 295.

Altho the *Atlantis* collected 48 specimens of this fine sea-star, all but 7 were taken between Caibarien and Matanzas on the northern coast and mostly in the Nicholas Channel, in 260-605 fms. One

small adult was taken in the Windward Channel, south southwest of Cape Maysi, in 1600-1800 fathoms. A very young individual was taken off Cienfuegos in 1075 fms. Both of these specimens from very deep water have the granules on marginal plates and actinal surface relatively coarser and less crowded. A fine small adult was found in 550 fms. off Cabo San Antonio, Pinar del Rio, while another occurred in 560 fms. off Puerto Tanamo and 2 others in 830 fms. off Puerto Cayo Moa, at the other end of the island. Off Bahia de Cochinos, southern coast of Santa Clara, a single fine adult was secured. The specimens range in size from R = 15 mm. to R = 110 mm. but they show little diversity. The stations where they occurred are 2970, 2987D, 2987E, 2988, 2989, 2990A, 2990B, 2991, 2992A, 2995, 3313, 3323, 3338, 3363, 3377, 3437, 3438, 3439, 3443, 3447, 3448, 3449, 3451, 3459, 3474, 3483 and 3485.

Nymphaster subspinosus

Pentagonaster subspinosus Perrier, 1881. Bull. M. C. Z., *9*, p. 21.
Nymphaster subspinosus Sladen, 1889. *Challenger* Ast., p. 295.

This species is even more common in Cuban waters than the preceding for the *Atlantis* took 71 specimens during her two voyages. All but 3 specimens were found on the northern coast of Cuba between Caibarien and Matanzas. At Cochinos Bay, on the southern coast of Santa Clara, 3 specimens were found in 220-320 fms. The bathymetrical range of *subspinosus* seems to be distinctly less than that of *arenatus*, for the latter is found from 260 down to 1600-1800 fms., *subspinosus*, seems to be restricted to the area between 150 and 380 fms. It is not strange therefore that the two species are rarely found at the same spot. They were taken together at Bahia de Cochinos and three times at Caibarien and points east of there. The specimens taken of *subspinosus* range from young ones with R = 15 mm. to very large ones in which R, if complete, would = 150 mm. There is a great deal of diversity in the development of the spines on the marginal plates but in adults they are conspicuous on both series. The stations where *subspinosus* was taken are 2963E, 2980B, 2981B, 2982D, 2983, 2983A, 2984, 2985, 2987, 2987A, 2987C, 3000, 3323, 3436, 3437, 3438, 3439, 3443, 3444 and 3448.

Rosaster alexandri

Pentagonaster alexandri Perrier, 1881. Bull. M. C. Z., *9*, p. 22.
Rosaster alexandri Perrier, 1894. *Travailleur* et *Talisman* Ech., p. 387.

On the day before she ended her 1939 cruise, the *Atlantis* rediscovered this interesting little sea-star off Bahia de Matanzas, Matanzas Province, in 190-240 fms. (Sts. 3478, 3479, 3480 and 3482). There are a dozen specimens ranging from R = 12 to R = 22 mm.; the last is the largest specimen of *Rosaster alexandri* yet taken but the generic and specific characters are not in any appreciable way different from those shown by smaller specimens. It seems clear therefore that Rosaster is not the juvenile stage of some larger Goniasterid.

Peltaster hebes

Verrill, 1899. Trans. Conn. Acad., *10*, p. 169.

There are two fine Peltasters in the *Atlantis* collection that seem to belong to this little known species, described from a single specimen, with R = 56 mm., taken by the *Albatross* at her St. 2668, off Georgia, in 294 fms. The smaller *Atlantis* specimen with R = about 45 mm. and r = 27 was taken at St. 2962B which is on the southern side of Cuba in the Bahia de Cochinos, Santa Clara Province, 180-190 fms. In its dry condition it is a light fawn color but a note with it says it was "pale pink above, extending slightly underneath", when taken. The larger *Atlantis* specimen is much bigger than Verrill's type, as it has R = about 65 mm. and r = 40. It was taken at St. 2995, on the northern side of Cuba, off Bahia Cardenas, Matanzas Province, 370-605 fms. It is pale yellow (dry), darkest on the superomarginal plates.

These specimens are much less pentagonal than Verrill's and in some details are dissimilar. But the large ventral pedicellariae and the adambulacral armature are so like Verrill's description, we are warranted in considering these West Indian specimens identical with his. The smaller specimen has very few dorsal pedicellariae (Verrill makes no reference to any) but the larger one has numerous, minute pedicellariae scattered all over the dorsal surface, even on the superomarginal plates. On the actinal surface there are very few however. The large pedicellariae beside the ambulacral furrows are very striking in both *Atlantis* specimens. Verrill's later conclusion (1915,

p. 222) that his *hebes* is identical with Storm's (1880, p. 90) *nidarosiensis* seems to me very dubious. Actual comparison of Norwegian and West Indian specimens is necessary.

Peltaster planus

Pentagonaster planus Verrill, 1895. Amer. Jour. Sci. (3) *49*, p. 135.
Peltaster planus Verrill, 1899. Trans. Conn. Acad., *10*, p. 170.

A single huge Goniasterid, taken by the *Atlantis* at St. 3306, off Playa Baracoa, Havana Province, in 330 fms., seems to be a large adult of this species. The only recorded specimen is the unique type, which was taken off Marthas Vineyard in 156 fms. It had R = 50 mm. and r = 35; hence R = 1.4r. Verrill described it as "pentagonal, with the sides only slightly incurved". That description applies well to the present specimen, which is nearly twice as big, for R = 90-100 mm. and r = 65. The vertical thickness in the *Atlantis* specimen is nearly 25 mm. It is yellow-brown in color (dry), somewhat lighter below. In life, according to the label with the specimen, the color was "pale yellowish gray, plain".

Altho so much bigger than Verrill's specimen, this one from Cuba corresponds well with it in its more important features particularly the uniform close-set covering of granules and the adambulacral armature. But Verrill says of his type "No pedicellariae could be found", whereas the *Atlantis* specimen has great numbers of minute pedicellariae all over the dorsal surface, save on the superomarginals, and scattered larger ones on the actinal plates. But no very large ones adjoin the ambulacral furrows as they do in *hebes*. Perhaps good series of specimens will warrant separating a northern and a West Indian species but meanwhile the name *planus* will serve for both.

Plinthaster dentatus

Pentagonaster dentatus Perrier, 1884. *Blake* Stell., p. 242.
Plinthaster dentatus Fisher, 1911. Bull. 76 U. S. Nat. Mus., p. 165.

The *Atlantis* met with this fine species on both of her voyages and brought back 17 specimens, ranging in size from a young one with R = 18 mm. to a very large adult with R = 53 mm. In their dry condition most of them are cream-color or pale yellow, but some are deep yellow or yellowish brown and several have a distinctly reddish tint. The most striking is an individual with R = 25 mm.,

which is light reddish-brown above and pale yellow on the oral surface; the reddish tint is very marked.

There is some notable diversity in form, since most individuals have the distal marginal plates more or less in contact. In typical examples, the four distalmost superomarginals on each side are in close apposition with their fellows, the abactinal plates being thus markedly cut off from contact with the terminal plate. In other individuals only 3 or 2½ pairs of plates are thus in contact. Generally the sides of the body, formed by the marginal plates are rather definitely and evenly concave but in some cases, they are very straight, while the terminal fourth of each ray projects somewhat abruptly from the angles of the pentagon. As a rule, the vertical thickness of the animal is only about .06-.08 of its diameter several specimens are stouter and have the marginal thickness .10-.12 of the diameter. In these specimens the form is more perfectly pentagonal, with the rays projecting but little and only the 2 distalmost pairs of superomarginals fully in contact, the third pair being more or less separated. The difference in appearance between the two extremes is so great that the question arises whether they are not really distinct species but the intergradation seems too complete to justify any separation.

Except for a single specimen taken in Bahia de Corrientes, Pinar del Rio Province, 615 fms., all of these Plinthasters were taken on the northern side of Cuba, south and southeast of Cay Sal Bank, in 240-665 fms. The station numbers are 2953, 2984, 2985, 2987, 2987A, 2987C, 2987D, 2992, 2992A, 2996, 3444, 3445, 3457 and 3472.

Litonotaster intermedius

Pentagonaster intermedius Perrier, 1884. *Blake* Stell., p. 243.
Litonotaster intermedius Verrill, 1899. Trans. Conn. Acad., *10*, p. 172.

In Verrill's important paper, in which he establishes the genus Litonotaster with Perrier's species as the type, he says he has examined Perrier's type, "now in the Museum of Comp. Zoöl." and that his specimens collected by the *Albatross* "agree closely with it". Perrier himself, in his original description, says there were "2 exemplaires" but he describes only one. It is greatly to be regretted that neither of these 2 specimens are now in the collection nor is

there any clue to their fate. It is fortunate therefore that the *Atlantis* has secured 6 specimens, 5 in 1938 and one more in 1939. The largest is not quite so big as Perrier's type (R = 27 mm.) and the arms are not quite so slender as his rather poor figures indicate. The figure of the upper surface shows about 34 superomarginal plates on each side of the pentagonal body but the text says there are 24. In the largest *Atlantis* specimen there are 24. Verrill says 2-4 pairs of the distal plates are in contact in the midradial line. Perrier does not mention, nor does his figure show, such a condition but the largest *Atlantis* specimen shows it clearly.

There is considerable diversity among the Cuban specimens in the extent of granulation of the abactinal plates. In the smallest (R = 19 mm.), nearly all the plates are bare at the center but have one or more series of nearly spherical minute granules around the margin. At the center of the disk and near the interradial margins, there are, here and there, plates wholly covered by granules. A second specimen, with R = 21 mm., has the same general character, and as the plates are somewhat larger, the bareness is somewhat accentuated. While all the specimens have suffered somewhat from abrasion, during their upward journey thru more than a mile of water, the bareness of the abactinal plates in these specimens is not due to that, save here and there. In the largest specimen (R = 25-26 mm.), however the upper surface is very fully granulated save for considerable abrasion. The other 3 specimens are intermediate in their granulation but seem to indicate that in youth the abactinal plates are bare or have only marginal granules, but granulation increases with growth and adults are fully granulated. The marginal plates in both series seem to pass thru a similar process of increasing granulation; in youth they have only marginal granules but granulation increases with age, especially in the interbrachial arc and on the inferomarginals and the lower half of the superomarginals. The actinal intermediate plates are rather sparsely covered, even in the smallest specimen, with more angular granules, which become more numerous as the individual increases in size.

Of the 6 *Atlantis* specimens, 5 were taken at St. 2970, in the Windward Passage, south of Oriente Province in 1600-1800 fms. The other was taken a little further west at St. 3355, off Bahia de Guantanamo, Oriente Province in 1070 fms.

Astroceramus brachyactis[1] sp. nov.

(Plate 6, fig. 3)

Arms 5; R = 30 mm.; r = 15; R = 2r; br at fourth superomarginal, 6 mm. Superomarginals only 9; beyond the third which is largest, closely in contact along midradial line; terminal plate conspicuous, on one arm with 3 short, stout, blunt spines. Superomarginals with scattered granules, 20-30 or more, chiefly grouped at the center or on the lower half of the plate, and a single marginal series along each of the 4 sides. Abactinal plates rather large (1-1.75 mm. in diameter), with the surface flat, but slightly shagreened rather than smooth. At the angles and here and there along the margins are very minute granules, but on only a few plates is there anything like a complete marginal series. Madreporite small, triangular, much nearer to the disk-center than to the superomarginals.

Inferomarginals corresponding very closely with the superomarginals in number, form, position and granulation, but the first and second are the largest rather than the third. Actinal intermediate plates rather few (35-40). The larger ones near the mouth have a marginal series of rather coarse granules while the surface of the plate is shagreened and carries 1-4 large granules and usually a single large, 2-jawed, spatulate pedicellaria. Distally (adjoining the marginals) the plates are rather small and pretty well covered with granules. They extend scarcely to the fourth inferomarginal on each side. Adambulacral plates with a furrow series of 5 or 6 rather stout, but relatively slender, blunt spines, the middle ones longest, those at each end of the series notably shorter. The surface of the plate carries a single very stout, somewhat flattened, blunt spine, scarcely a millimeter long but nearly half a millimeter wide. Very rarely a second much smaller spine stands beside the big one. The remaining surface of the plate is occupied by 6-10 coarse granules, slightly larger and less spherical than those on the actinal plates. Oral plates not conspicuous; in this specimen they have been crushed down into the mouth together; they evidently carry a marginal series of compressed prismatic spines, rounded at the tip, and a number of low, stout prismatic spines on the surface. Evidently the form and arrangement of these various oral spines are essentially as described by Fisher for the Hawaiian genotype.

Color of dry specimen light fawn, orally with a yellowish cast but aborally with a darker, definitely reddish tint, especially on the granules which border the abactinal and superomarginal plates.

Holotype, M. C. Z. No. 3918, from Station 3302, off Playa Baracoa, Havana Province, 230 fms.

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(1) βραχύς = *short* + ἀκτίς = *ray*, in reference to the short arms.

It is indeed extraordinary that this genus, based on a single specimen from the Hawaiian Islands, should be rediscovered in the West Indies, and again but a single specimen be secured. But even more remarkable is it that the *Albatross* met with Astroceramus twice in the Philippines and in each case a single specimen only was taken and that one represented a species quite distinct from any of those previously known. For another species was known, named by Koehler *Astroceramus fisheri,* taken by the *Investigator* (3 specimens) southwest of Travancore, India, and also by the *Siboga* (2 specimens) in the Dutch East Indies. Still another species, *A. cadessus* Macan, was taken (2 specimens) by the John Murray Expedition near the Maldive Islands. The West Indian species is more like the Hawaiian, *callimorphus,* than it is like any one of the oriental species. Indeed it is clearly distinguished by two characters only; the shortness of the arms and the presence of but a single heavy spine, instead of 2, on the actinal surface of the adambulacral plates. These characters also set it apart from the oriental species but it differs from them further in the granulation of both marginal and abactinal plates. The Cuban specimen is the smallest Astroceramus yet taken. The Indian species, *fisheri* and *cadessus* are nearest, as the smallest of the *Investigator's* 3 specimens has R = 47 mm. and the smaller *cadessus* has R = 35 mm. The Hawaiian and Philippine specimens have R = 73-82 mm. It is of course possible that the *Atlantis* specimen is not adult but there is no obvious evidence of immaturity.

Circeaster occidentalis[1] sp. nov.

(PLATE 4, FIG. 2)

Arms 5; R = 93 mm.; r = 38; R = not quite 2.5r; br at fifth superomarginal 18 mm.; R = 5 br. The arms, measured from the region of the fifth superomarginal are about 50 mm. long, rather definitely set off from the disk which is a pentagon with sides about 50 mm. (or a little more) long. Disk relatively flat but more or less elevated (in the various specimens) either at center or on the papular areas, or both. It is closely covered with small, flat, smooth plates, oval, elliptical or more or less circular, 1-3 mm. in diameter; each plate is surrounded by a marginal series of granules, more or less spherical here and there but for the most part flattened and scale-like. Most of the plates carry, each a single very large 2-jawed

(1) *occidentalis* = *western*, in reference to its occurrence in the West Indies, the two known species of the genus occurring in the Indian Ocean.

pedicellaria; each jaw is about as wide as long and its margin is serrate with about 5 teeth; the jaws are half a millimeter wide or more. When no pedicellaria is present the surface of the plate is often perfectly smooth but more commonly 1-4 spherical granules adorn it. Frequently one or more granules occur on the plates having a pedicellaria. On the arms the plates increase abruptly in size (up to 5 mm. in diameter) but soon decrease and disappear at about the 15th superomarginal, as the marginal plates of the two sides meet at about that point and continue in contact to the arm-tip. The 22-24 superomarginals are proximally somewhat higher or wider than long and slightly convex, but distally, where they meet in the midline they are 2-3 times as wide as long. These short wide plates are quite smooth and without granules save on the inner and proximal margins, where a few minute granules occur. Passing from the arm-tip to the disk these marginal granules become larger and more numerous and soon form complete marginal series around each plate. The surface of the plate also bears somewhat larger granules, increasing in number along the sides of the disk, where the large plates may have 40-50 granules, but they are wellspaced and never crowded; there may also be 1-4 small pedicellariae on each plate. Terminal plate not conspicuously large but very evident, rounded truncate-conical. Madreporite rather large, 4-5 mm. in diameter, its distal margin about 15 mm. from the marginal plates.

Inferomarginals similar to those of the upper series in number, form and covering, but with more granules and pedicellariae. As they are not of the same width as the corresponding superomarginals, they match them evenly only here and there; as a rule each inferomarginal subtends the suture between two superomarginals. Actinal intermediate plates numerous, extending well out on the arm, the series adjoining the marginals continuing to the 16th inferomarginal. The plates are so covered with irregular tubercles, coarse, angular granules, and pedicellariae that their outlines are not easily made out. Each plate carries a huge bivalve pedicellaria at its center and this is closely surrounded by rounded tubercles, while angular granules form a marginal fence around each plate. The pedicellariae vary of course with the size of the plate but the largest ones have valves 1.5 mm. wide and about half as high; the edge of the jaw is either finely serrate or smooth. Adambulacral plates with a big pedicellaria on the actinal surface and tubercles and granules like those on the actinal plates. The armature on the furrow margin consists of a series of 6 or 7, long, stout prismatic spines with thick, rounded tips; these tips are pitted and creased on the free end to a remarkable degree especially on the spines along the proximal half of the furrow. Oral plates not swollen but somewhat depressed; marginal series of spines similar to the furrow spines but notably heavier; terminal pair largest, markedly compressed; all have the tips conspicuously pitted and furrowed. Surface of each plate with a few low angular tubercles and, at least one of each pair (and often

both) carries one of the big pedicellariae. Color, dry, very light yellowish-brown or dirty cream-color above; lower surface, except of the free arms, definitely reddish especially near the disk margins.

Holotype, M. C. Z. No. 3819, from St. 2990B, off Puerto Sagua la Grande, Santa Clara Province, 415 fms.

There is a somewhat smaller paratype from the same station; a second still smaller (R = 70 mm.) from St. 3305, off Playa Baracoa, Havana Province, 330 fms. A third, with R = 80 mm. from St. 3474, off Bahia Cardenas, Matanzas Province, 490 fms., is bright yellow-brown in color and has the arms notably slender. There is another specimen in the M. C. Z. collection with R = 70 mm., taken by the *Blake* in 1880 at St. XVIII, northeast of Ambergris Cay, British Honduras, 600 fms. Apparently this specimen was not sent to Perrier with the *Blake* sea-stars, but at sometime it was seen and examined by Verrill and he wrote on the back of the *Blake* collection label, "sp. nov. allied to Hippasteria". This specimen may also be considered a paratype.

The discovery of this genus in the West Indies is most interesting for it was described by Koehler (1909, p. 83) on the basis of two large sea-stars from the southeastern part of the Arabian Sea, off Goa and the southern Malabar coast, in 912-1053 fms. Altho the two are clearly congeneric, they represent two distinct species, and neither has been met with since. The *Albatross* did not find Circeaster in the Philippines nor did the John Murray expedition find it in the Arabian Sea and northwestern Indian Ocean. The West Indian species is easily distinguished from its oriental congeners by its narrowers arms, more abruptly set off from the disk, with far fewer abactinal plates, and many distal superomarginal plates in contact medially. Further obvious differences are evident on the actinal surface and in the armature of the adambulacral plates.

The 5 specimens of *occidentalis* at hand show some diversity in details but nothing remarkable. The one from St. 3305 shows no hint of red or yellow but tends to be fawn color, more grayish brown actinally, and brighter brown on the disk. Its arms merge into the disk more gradually so that the latter is less markedly pentagonal, its sides tending to be a trifle concave. The pitting and creasing of the adambulacral and oral spines is inconspicuous or wanting. In the smallest individual, the *Blake* specimen from British Honduras, the dorsal plates on the rays are relatively few and extend out only to the tenth superomarginal. The pedicellariae are somewhat fewer

and stouter than in the other specimens. The difference in general appearance between this individual and the one from St. 3305 is rather striking but the others are intermediate and there can be no question that all represent a single species. One striking feature, common to all of these dry specimens, is the way in which the distal part of each ray is turned upward to stand more or less vertically as compared with the disk. This is least marked in the rather aberrant specimen from St. 3305, which, by the way, occurred in the shallowest water.

Anthenoides peircei

Perrier, 1881. Bull. M. C. Z., *9*, p. 23.

The *Atlantis* has brought back a very notable series of this rare sea-star, including the largest yet taken. There are 19 specimens in all ranging from young ones with R = about 40 mm. to the maximum, R = 160-165 mm. It is interesting to note that the proportion of the lesser to the greater radii is essentially the same in the largest as in the smallest, R = 2.5-2.75r. The growth changes are not remarkable and are almost wholly due to the development of the granular membrane which more or less obscures plate-outlines in adults, and the increase in number of pedicellariae and of spines on the inferomarginal plates. The last feature shows much diversity among the larger specimens. Enough color is still present in the dry specimens to demonstrate that in life the upper surface of adults is orange or vermilion red, while the lower surface is cream-color or yellow. In young individuals (R = about 40 mm.) there is apparently little pigment, the dry specimens being dirty white or dingy gray-brown. A specimen with R = 55 mm. is very pale brown above and cream-color beneath, while another of about the same size is distinctly tinted with orange on the upper side.

Of the 19 specimens, 4 were taken in the Bahia de Cochinos, southern side of Santa Clara Province. All of the others were dredged on the northern coast of Cuba between Cayo Romano, Camaguey, and the Bahia de Matanzas. The bathymetrical range was notably small as all were taken between 190 and 320 fms. The station numbers are 2962C, 3319, 3323, 3387, 3391, 3394, 3396, 3408, 3413, 3418, 3422, 3480 and 3482. Apparently tho well distributed along the north-central coast, this sea-star is not very common anywhere as not more than 2 specimens were taken at any one station.

Family Oreasteridae

Oreaster reticulatus

Asterias reticulata Linnaeus, 1758. Sys. Nat., ed X, p. 661.
Oreaster reticulatus Müller & Troschel, 1842. Sys. Ast., p. 45.

There are 23 specimens of this, the commonest West Indian sea-star, ranging from 25 to 180 mm. in length of ray. They were collected in 1938 at "Siguanea Bay, shore line to 3 ft. deep", on the "southwestern coast of Cuba"; and in 1939 at Sts. 3347-3350, inside Cabo Cruz, Oriente Province, 11.5-13 fms. The growth changes are interesting but the adults show very little diversity.

Family Ophidiasteridae

Linckia bouvieri

Perrier, 1875. Arch. Zoöl. Exp., *4*, p. 414.

From St. 3479, off Bahia de Matanzas, 210 fms., there is a single, small but quite typical example of this rare sea-star, with R = 47 mm. The arms are nearly cylindrical, 6-7 mm. in diameter at base, slightly flattened orally and distinctly smaller near the tip. The oral surface is nearly cream-color but the upper side is a reddish fawn color darkest on some of the swollen plates characteristic of the species. There are 8-10 of these plates on the disk, the largest more than 2 mm. in diameter.

Ophidiaster alexandri

Verrill, 1915. Bull. Univ. Iowa, Lab. Nat. Hist., *7*, p. 91.

This interesting and apparently rather rare sea-star, not previously represented in the M. C. Z., was taken by the *Atlantis* twice in 1938 and twice in 1939. The four stations (2980B, 2984, 3302, 3480) are all on the northern coast of Cuba, between Punta Alegre, Camaguey Province, and Playa Baracoa, Havana Province, in 200-250 fms. Two of the specimens are small (R = about 40 but no two rays are of exactly the same length), have rather numerous pedicellariae on the disk and only about half a dozen papulae in the poriferous areas. The other 2 specimens are larger than Verrill's type, having R = 73-93 mm., have few pedicellariae on disk or none, and about a dozen papulae in each poriferous area. All the specimens

are reddish fawn color above and whitish, yellowish or very pale brown beneath. The madreporite is distinctly but not conspicuously yellowish. In the small specimens and in the largest, pedicellariae form a notable series along each side of the ambulacral furrow but in the fourth specimens, pedicellariae are few and far between. It is notable that Verrill makes no reference to pedicellariae indicating that they were lacking (or nearly so) in his specimen. The "very small acute spinelets" alternating with "much larger and longer, stout tapered spines", described by Verrill seem to be absent in the *Atlantis* specimens, unless they are represented, in the smaller of the two large specimens, by short but rather stout, pointed spinelets, alternating with the normal spines on the actinal surface of many distal adambulacral plates. Verrill seems to have had several specimens for examination but his description is brief and not very satisfactory, so it is not impossible that these Atlantis Ophidiasters are not identical with his.

Ophidiaster pinguis[1] sp. nov.

(PLATE 5, FIG. 2)

Arm 5; R = 82 mm.; r = 18; br = 20; R = 4.5r or 4 br. Disk, aside from the swollen bases of the rays, small, covered by relatively few, irregular unequal plates whose outlines are more or less concealed by a finely granulated skin which covers the whole animal. The minute granules of this skin are largest among the papulae and on the convexities of many of the skeletal plates. They are conspicuously larger around the anus which is closed by half a dozen (or more) smooth, mostly triangular, thick plates, .75-.80 mm. long, the base nearly as wide. Madreporite large and swollen, 7 mm. long by 3.5 wide, closely covered with very narrow irregular ridges, separated by equally narrow and irregular furrows.

Arms terete, notably swollen at base, where they are orally flattened, tapering rather uniformly to the tip, 3 mm. from which the thickness is 5 mm. There are 8 very conspicuous longitudinal series of areas of papular pores; the 2 adjoining the carinal series of abactinal plates have the papular areas near base of arm 3.5 mm. wide and over 1 mm. long, with 12-15 small papulae; distally these areas decrease markedly in size, become as long as broad and have only 3-5 papulae. The second and third series of papular areas are

(1) *pinguis* = *fat*, in reference to the swollen arm-bases.

similar to the uppermost but the areas are not quite so large. The fourth and most adoral series has the areas much smaller, with 8 or 9 papulae at first, decreasing to 2 or 3 distally. Near the middle of the arm and distally single pores are frequent between this series and the actinal plates but they seem to be "strays" from the serial areas. Abactinal and lateral plates of the arm numerous but small and swollen, basally in regular, narrow, longitudinal series but distally they become more irregular in form and position. There are no tubercles, spinelets, or pedicellariae on the dorsal surface.

Actinal intermediate plates rather numerous, in 5 series interradially; one series accompanies the adambulacrals nearly to the tip of the arm; a second extends beyond the middle of the arm; a third extends at least to the middle; the fourth is much shorter with 9 or 10 plates; the fifth is very short with only 4 or 5 plates. All of these plates are more or less concealed by the granular coating which is much coarser than on the abactinal surface; it is particularly coarse on the convexities of the plates and especially interradially. Just back of the oral plates the granules are very large, flattened and thick, like short, rounded scales. The plates adjoining the adambulacrals usually carry pedicellariae (not more than one to a plate) and a few plates of the second series may have them. These pedicellariae are of the type common in Ophidiaster; they are about 1 mm. long with the width half as much; the alveolae are nearly or quite straight.

Adambulacral plates as usual in the genus. Each plate has a pair of flat, subequal, erect furrow spines without granules between, and, on the actinal surface of the plate, a more or less appressed, flattened, elliptical spine, about a millimeter long by one-third as wide; of course distally these spines are smaller, becoming short and thick. On the first 3 or 4 adambulacrals, a second similar but smaller spine is present. Oral plates small, their outlines completely obscured, their armature similar to that of the first adambulacrals. Color above light reddish brown; orally very light yellowish brown; the two shades merge on the sides of the rays without sharp contrast; madreporite, brownish yellow.

Holotype, M. C. Z. No. 3820, from St. 3324, in the Bahia de Cochinos, southern coast of Santa Clara Province, 320 fms.

This is a very well-marked species, from an unusually great depth for a member of this shallow-water family. The adambulacral and oral plates and the pedicellariae are almost exactly as in *alexandri* but the general form and the character of the dorsal surface are so very different, the two species cannot be confused.

Family Poraniidae

Marginaster pectinatus

Perrier, 1881. Bull. M. C. Z., *9*, p. 16.

This species, hitherto known only from the unique holotype in the M. C. Z., is represented in the *Atlantis* collection by a very fine specimen, twice as large. It was taken at St. 2980, in the Old Bahama Channel, off Punta Alegre, Camaguey Province, 250 fms. It is almost perfectly pentagonal, tho the sides are slightly concave, and is 20 mm. across (R = 10 mm.±) and fully 5 mm. high. The color is a light pink with the marginal plates and spines white. Perrier's original description applies well to the present specimen except that there are no spines whatever on the actinal intermediate plates. The holotype is in poor condition and has lost all of the marginal spines but these are well developed and more or less conspicuous in the *Atlantis* specimen. The spinelets of the abactinal surface are also numerous and give a rough appearance to the upper side of the sea-star while the lower surface is remarkably smooth. The holotype is obviously a young individual. Whether the present specimen is adult or not it is impossible to say but it is not unlikely that it also is immature.

Family Asterinidae

Tremaster laevis[1] sp. nov.

Rays 5. R = 24 mm.; r = about the same. In life the form was probably nearly circular with a diameter of about 50 mm. and a vertical height of about 5 mm. In its present contracted and dry condition it is 29 mm. long, 15 mm. wide and 19 mm. high. Abactinal surface covered with overlapping plates, the proximal margins overlying the distal, the adradial margins overlying the abradial. The carinal series on each ray are wider than long, as are also several of the interradial plates nearest the disk, but all other plates (except some small ones near the disk margin) are longer than wide. The disk itself, if we limit it for convenience to the area within the circle of interradial slits, is covered by 11 large plates, a suranal adjoining the somewhat excentric anus, 5 large more or less hexagonal interradials, about as long as wide in one of which is placed the small madreporite, and 5 large radials, each wider than long (3 mm. wide × 2 mm. long). Anus relatively large, apparently closed by 4

(1) *laevis* = *smooth*, in reference to the character of the abactinal plates.

small, triangular valves which are partially concealed by half a dozen short, thick spines borne on the margins of the adjoining suranal and interradials. The plates of the entire upper surface are very smooth and more or less shining when dry, completely without granules. The larger plates near the disk have on the proximal margin a single large marginal spine, which is flattened, and lies appressed against the next plate and pointed towards the disk. The basal carinal plate has 2 such spines, well separated from each other. The minute marginal plates each carry a short, flat, truncate spinelet and these form a very delicate fringe around the animal. The generically characteristic interradial slits are small but conspicuous, located about 5 mm. from the anus. Each is 2 mm. long by less than 1 mm. wide, and more or less obscured, but by no means closed, by half a dozen small flat spinelets on each side.

Owing to the condition of the specimen it is difficult to make out the details of the actinal surface, but the actinal intermediate plates are numerous and each carries at its distal end a single, appressed, blunt spine nearly as long as the plate. Adambulacral plates short and wide; each carries a long blunt spine like those of the actinal plates but still larger, and on its inner face a similar but very much smaller spine. Oral plates rather large; each carries at its tip a very large spine, and along its margin 2 or 3 very small spines, above which on the plate's surface, is a series of 2 or 3 spines, similar to those of the adambulacrals. The interradial slits open just back of the oral plates. Color, brownish-yellow; ivory white where the surface is rubbed off.

Holotype, M. C. Z. No. 3821 from St. 3326 in the Bahia de Cochinos, southern coast of Santa Clara Province, 265 fms.

The rediscovery of this genus after the lapse of many years is most interesting especially since the locality is so far from that were Tremaster has hitherto been taken, and the Cuban species is so obviously different from Verrill's (1879) species. The genus was based on 3 specimens taken by Gloucester fishermen, at different localities on the fishing grounds east and southeast of Nova Scotia, in 150-250 fms., in 1879. The northern specimens were much larger than the present individual but Verrill's statements are confusing for he says "greatest diameter of the largest specimen, 112 mm." which would indicate a radius of about 55-60 mm. and then he says "A smaller specimen has the greater radius 63 mm.; lesser 55". However it is evident that the northern species reaches a size fully twice that of the present specimen. There are some very obvious differences in structure, such as the following: In *Tremaster mirabilis* Verrill "all the dorsal plates are covered with small, scattered granules" while in *laevis,* the plates are very smooth; in *mirabilis,*

the radial plates have 8-10 (1 or 2 in young specimens) small spines along the free edge, while in *laevis* there is usually but 1 and never more than 2; in *mirabilis*, the adambulacral plates carry 4 spines, in *laevis* only 2; in *mirabilis*, the interradial slits are said to be "large and conspicuous" and "large and rounded" but in *laevis* they are small and narrow.

Apparently the sea-stars of this genus live closely appressed to the surface of rocks and are only to be taken when a fish-hook catches under the margin and pulls them off the rock, or the entire rock is brought up in the trawl. Hence their great rarity in collections. The iterradial slits probably serve for aeration of the lower surface while the sea-star is closely appressed to the rock and this suggests that the eggs undergo development in that sheltered area around the mouth.

Family Echinasteridae

Echinaster modestus

Perrier, 1881. Bull. M. C. Z., *9*, p. 7.

The Atlantis secured but a single specimen of this little known species but it is of special interest, as it is an adult and shows well the particular characters which mark the species. The arms are rather short and stout (R = 40 mm. or more, br = about 13 mm., hence R = 3r) and the skeleton is made up of narrow ossicles, so that the areolae are conspicuously large. The spines are very short and small but rather stout and acute. Verrill (1915) refers only to the *Blake* specimens, so it would seem neither the Bahamas Expedition nor the *Albatross* met with the species, which we may therefore consider as, for some unknown reason, quite a rarity. The present specimen was taken at St. 3303, off Playa Baracoa, Havana Province, in 260 fms. Whatever its color may have been in life, it is now light yellowish-brown, "museum color", quite unlike most West Indian Echinasters which are commonly quite dark even when dried.

Echinaster sentus

Asterias sentus Say, 1825. Jour. Phila. Acad., *5*, p. 143.
Echinaster sentus Lütken, 1871. Vid. Med., p. 284.

This common sea-star is represented in the *Atlantis* collection by 9 typical examples from "along shore, near Indian River, Siguanea Bay, Isle of Pines", a young (R = 22) but very typical, stout ex-

ample from "inside Cabo Cruz, Oriente Province, 11½-13 fms." (Sts. 3347-3350), and an aberrant specimen with a rather light skeleton and comparatively slender spines, labelled dubiously as from St. 3397, off Cayo Coco, Camaguey Province, 180 fms. This is an excessive depth for this species and there is probably some mistake. On the other hand the peculiarities of the skeleton might be explained by the unusual depth.

Henricia antillarum

Cribrella antillarum Perrier, 1881. Bull. M. C. Z., *9*, p. 8.
Henricia antillarum Verrill, 1914. Harriman Exp. Starfishes, p. 210.

In 18938 only 2 specimens of this sea-star were taken but in 1939, it was met with at 14 stations, and there are now 24 specimens at hand. Two other species of Henricia were taken by the *Atlantis* but it is interesting to note that neither occurred at the same station with *antillarum*. As the species of Henricia are notoriously variable and difficult to distinguish, it may be worth while to make clear how the 3 West Indian species are to be recognized. For this purpose, the following key has been prepared.

Rays usually (perhaps always) 5; no spinelets of abactinal surface long and terminating in 3 (or 4) slender divergent needles.

Meshes of skeleton small with small (rarely big) papulae; spinelets long and acicular, grading on the actinal surface into the adambulacral armature. . . . . *antillarum*

Meshes of skeleton large with big papulae; spinelets swollen, rough, orally very short and widely spaced, the adambulacral spines abruptly bigger. . . . . *microspina*

Rays usually (perhaps always) 6; spinelets relatively long and generally ending in 3 (or 4) divergent needles; adambulacral spines abruptly bigger, with thick, rounded, more or less capitate tips, covered with sharp points. . . . . *sexradiata*

The specimens of *antillarum* in the Atlantis collection show great diversity in size, form and color, and the line separating them from *microspina* is by no means sharply drawn, but nevertheless it is probable that it really exists. The smallest *antillarum* has R = 13 mm. with br about 2; it is dingy gray in color as are several other small specimens. The largest individual has R = 100-110 mm. with br

about 10; it is orange yellow in color becoming paler distally on the arms; madreporite is deep yellow. The intermediate specimens are dingy shades of light brown or cream-color but have the characteristically slender arms. One specimen however from St. 3303, off Playa Baracoa, Havana Province, 260 fms., is notable for its short arms and unusually dense spinulation, especially on the oral surface. The arms are only about 48 mm. long (2 have been bitten or broken off near the tip) but are 9 or 10 mm. in diameter at base. The color is wood-brown. In view of the diversity and hybridization known (or suspected!) in the genus it seems best to treat this individual as an aberrant *antillarum*.

The other specimens were taken either in the Bahia de Cochinos, southern coast of Santa Clara Province, 195-300 fms., or, for the most part, along the northern coast of Cuba, between long. 79° 28′ and 82° 33′, 255-665 fms. The station numbers are 2993, 2996, 3303, 3319, 3325, 3436, 3437, 3438, 3443, 3446, 3447, 3448, 3449, 3451, 3459 and 3485.

Henricia microspina

Verrill, 1915. Bull. Univ. Iowa, Lab. Nat. Hist., 7, p. 48.

Verrill does not point out a single feature by which his proposed species is to be distinguished from *antillarum* but comparison of 33 specimens in the *Atlantis* collection, with the 24 specimens of Perrier's species convinces me that the two forms may properly be considered distinct species. The essential differences are pointed out in the above given key.

The Cuban specimens range from young ones, with R = 18-20 mm. to adults with R = 75-80 mm. There is some diversity in the slenderness of the arms for the largest specimen, with R = 80 mm. has br = nearly 12 mm. or R = 7 br, while another with R = 75 mm. has br about 9 mm. or R = 8 br. and a third has R = 54 mm., br = 6, R = 9 br. The smaller specimens have the slender type of arms. The color of these specimens ranges from pale gray or cream color through various shades of yellow or brownish to dark reddish brown. That the present color has little relation to the color in life is well shown by the fact that there are three adults labelled "lemon-yellow in life"; one is now brown-orange, a second is dull yellowish brown (rather light) and the third is dull dark reddish-brown. Specimens with R = 30 mm. or less, seldom show the species characters clearly and their accurate determination is very difficult.

Most of the specimens of *microspina* at hand were taken along the northern coast of Cuba between 78° 14′ and 81° 29′ W., in 175-390 fms. The species in on the whole a more shallow water form than the preceding but the bathymetrical ranges overlap broadly. However, as already stated, the two forms were never taken at the same station, but 2 specimens of *microspina* were taken in the Bay of Cochinos on the southern side of Santa Clara Province and *antillarum* was also taken in the Bay. The station numbers for *microspina* are 2950, 2961D, 2963B, 2980B, 2982A, 2985, 2987C, 2988, 3000, 3335, 3394, 3408, 3423, 3427, 3428, 3431, 3435, 3439, 3450, 3465, 3467, 3479 and 3482.

Henricia sexradiata

Cribrella sexradiata Perrier, 1881. Bull. M. C. Z., *9*, p. 8.
Henricia sexradiata Verrill, 1914. Harriman Exp. Starfishes, p. 371.

Verrill seems to have had an indefinite idea as to the characters of this species and says (1915, p. 48) "the possession of six rays cannot be regarded as a specific character, especially in autotomous species", but there are sea-stars in which 6 rays occur regularly as a species character and it is more than possible that this Henricia is one. Verrill makes the indefinite statement "Rays variable in number most frequently there are six" but he does not cite a specimen with any other number and it is probable he did not distinguish clearly between *sexradiata* and *microspina*. He makes no reference to the notable difference between the spinules of the two species. At any rate, the 3 specimens of *sexradiata* in the M. C. Z., Perrier's types, and the 2 specimens in the *Atlantis* collection all have 6 rays.

The Atlantis specimens are from St. 3482, off Bahia de Matanzas, Matanzas Province, 190 fms. With them were taken 2 young individuals of *microspina* but so far as these specimens are concerned the two species are easily distinguished. The specimens of *sexradiata* are obviously young and each has 6 rays. They are pale gray or nearly white in color. In the smaller specimen the rays are approximately equal in size and about 10 mm. long. The larger specimen is obviously the result of an autotomous division, as 3 rays on one side are 14 mm. long, while the 3 opposite rays are only 7. Under a

magnification of 40 diameter, the difference in spinulation between these 2 specimens and the young *microspina* from the same station is very striking.

Family Solasteridae

Solaster caribbaeus

Verrill, 1915. Bull. Univ. Iowa, Lab. Nat. Hist., 7, p. 54.

The *Atlantis* took a single specimen of this Solaster in 1938 at St. 2991, off Bahia de Santa Clara, Santa Clara Province, 475 fms., but she was not so fortunate as to meet with it in 1939. This individual is of special interest as it is the first adult to be secured, for Verrill says all of his specimens were quite young. He carelessly fails to say just where or at what depth they were taken. In what is supposedly his largest specimen R = 36 mm., r = 14, R = 2.6r.

In the present specimen, there are 8 rays. R = 63 mm., r = 21, br = 17; R = 3r or 3.7 br. The adambulacral armature is as described by Verrill, only the furrow series on the basal part of the arm usually has 5 spines and the transverse actinal comb may have 5; this is quite in accordance with the larger size of the present specimen. The oral spines are much more numerous than in the young, as there are 8 on each side, the distal 4 being quite small, and there is a series of 4-6 (or even 8, the 2 distalmost very small, on one jaw) rather similar spines on the distal adradial side of each oral plate. The color of the dry specimen is light yellow-brown, typical "museum color".

Lophaster furcifer

Solaster furcifer Düben and Koren, 1846. K. Svensk. Vet. Akad. Handl. 1844, p. 243.

Lophaster furcifer Verrill, 1878. Amer. Jour. Sci. (3), *16*, p. 214.

A small Lophaster, with R only 23 mm. is best referred to this species for the present. A good series of adult specimens would very possibly demonstrate that the Cuban form should rank as distinct from its northern congener. The present specimen was secured at St. 2995, off Bahia Cardenas, Matanzas Province, 370-605 fms., on March 16, 1938. In 1939, no Lophasters were taken.

Family Korethrasteridae

Remaster palmatus

Korethraster palmatus Perrier, 1881. Bull. M. C. Z., *9*, p. 12.
Korethraster (Remaster) palmatus Perrier, 1894. *Travailleur* et *Talisman* Ech., p. 161.
Remaster palmatus Verrill, 1915. Bull. Univ. Iowa, Lab. Nat. Hist., *7*, p. 55.

It is most fortunate that the *Atlantis* took a fine example of this interesting sea-star for the original *Blake* specimens have disappeared and the genus is not represented in the M. C. Z. The specimen at hand has R = 13 mm. and r = 5, indicating that it is of about the same size and proportions as Perrier's type. The characteristic dorsal paxillae and the remarkable, flat adambulacral and marginal spines are for the most part admirably preserved. The rays are a little wider distally and blunter than in Perrier's figure (1884, pl. VIII, figs. 5 and 6) and the "interradial groove" is evident in only one interradius. The dry specimen is pale cream color. It was taken at St. 3323, in the Bahia de Cochinos, southern coast of Santa Clara Province, 290-320 fms.

Perrier's treatment of this species was careless and unfortunate. In the original description (1881) he says R = 47 mm., r = 14 mm., R = 3r. In 1884, he has it R = 14 mm., r = 47 mm., R = 3r. In 1894, he tries again and has it R = 14 mm., r = 4 mm. 7, R = 3r. Verrill, who apparently examined and redescribed the type, says (1915, p. 55) "radii 4.7 mm. and 14 mm.; ratio, 1:3". The fate of the 5 *Blake* specimens is an inexplicable mystery; they have not been in the M. C. Z. collection since 1905, at least.

Family Pterasteridae

Pteraster caribbaeus

Perrier, 1881. Bull. M. C. Z., *9*, p. 13.

A very good example of this species was secured at St. 2987C, in Nicholas Channel, south of Cay Sal Bank, 300-315 fms. It is nearly the size of Perrier's type and is well preserved. The large white epioral spines with the still larger innermost oral spines are very distinctive. From St. 3437, off Caibarien, Santa Clara Province, 260 fms., there are 2 small Pterasters, with R about 13 mm. which are probably young *caribbaeus*, but their condition is poor and it is not certain that they are to be correctly referred to that species.

Pteraster militarioides[1] sp. nov.

Rays 5. R = 20 mm.; r = 10 mm.; br = 11 mm.; R = 2r. Form distinctly stellate, moderately swollen, the paxillae with stalks about half as long as the spines they bear. In general, so similar to *militaris* that a detailed description would be superfluous. The superoral spines are long, slender, and terete; oral spines 6, very small, more or less fully united by a membrane, the innermost, which is largest, is only about half as long as the superoral. Adambulacral spines 6 or 7, all very slender and acicular; the outermost is longest of course, and reaches its maximum length at about the fifth or sixth adambulacral plate. Actinolateral membrane indicates the boundary of the disk as seen from below. Color of holotype pale yellow-brown ("museum color"); the four smaller paratypes are pale gray.

Holotype, M. C. Z. No. 3822, from St. 3436, off Caibarien, Santa Clara Province, 255 fms.

The temptation to refer this Pteraster to the comparatively well-known northern species has been strong but comparison with specimens of *militaris* make it improper. The difference in the character of the spinulation, particularly the actinolateral and oral spines, is too great. Were there but a single specimen of the Cuban form the decision might be otherwise, but the 4 paratypes, altho all are much smaller than the one described, are essentially like it and show that the slender spines and spinules are specific and not individual characters. All of the material is from the same region, the northeastern coast of Santa Clara Province, 295-405 fms. (St. numbers 3439, 3446, 3448 and 3451). The smallest specimen (R = 11 mm.) is nearly pentagonal, the next (R = 12 mm.) is less so, the next (R = 14 mm.) has r = 8 and the largest has R = 15 mm., r = 8, R = 1.9r.

Pteraster rugosus[1] sp. nov.

(Plate 6, fig. 1)

Rays 5, short and wide. R = 21 mm., r = 14 mm., R = 1.5 r. Upper surface well arched, almost swollen. Paxillar stalks rather stout, about as long as the 5-8 not very slender spines they carry. There are no muscle bands connecting the tips of these spines but the latter

(1) *militarioides* = like *militaris;* the resemblance to the northern species is so striking.

(1) *rugosus* = *rough,* in reference to the conspicuously coarsely spiny aboral surface.

tend in preserved specimens to lean inward towards each other and form a projecting tuft 2 mm. or more high. It is these tufts which give the roughness to the aboral surface. Dorsal membrane very thin with numerous minute spiracula. Osculum evident but not very large, surrounded by 5 ill-defined valves, each including 5 or 6 spines like those of the paxillae. Disk very evidently bounded by the actinolateral membranes, which project in each interradius nearly 2 mm., as seen from above.

Oral surface quite flat completely covered by the actinolateral membranes, the spines of which are somewhat flattened and taper but little to a blunt or truncate tip. Adambulacral spines 7 or 6 (including the actinolateral), slender but blunt, the innermost 2 much shorter than the others. Aperture papilla small, somewhat triangular but with rounded margin and angles. Oral spines 7 or 6, like the adambulacrals, the 2 innermost (on each plate) longest and about equal to the very stout epiorals which are white at base but clear like glass at the thick but very acute tip, which is not at all 3-sided. Color white with a distinct lavender or pinkish cast, except along the ambulacral furrows where the tint is distinctly yellowish.

Holotype: M. C. Z. No. 3823 from St. 2980, off Punta Alegre, Camaguey Province, in the Old Bahama Channel, 250 fms.

There are 11 other specimens which may be referred to this species of which half a dozen may be considered paratypes. They range in length of R from 10 to 20 mm. and resemble the holotype in every way, save color; 4 are dull lavender-gray, 1 is wood brown and 1 is yellowish with a lavender cast. The remaining 5 specimens are small (R = 9-16 mm.) and in such poor condition that they are not typical. All of the material was taken along the northern coast of Cuba between 78° 40′ and 82° 34′ W., in 170-255 fms. The station numbers are 2980, 3000, 3302, 3465, 3478, 3479 and 3480.

In my key to the species of Pteraster (1908, p. 286), this species runs down easily to *pulvillus,* while in Fisher's (1911, p. 368) key, it runs down to a choice between *pulvillus* and *temnochiton.* The shape of the epioral spine and the character of the paxillae, not to mention the general facies and the locality, show it is not the latter. The absence of muscle bands in the membrane over the paxillae, the conspicuous lateral fringe and the general fascies make it fairly certain that this is not *pulvillus* but larger specimens and better series for comparison may prove this decision is wrong.

Pteraster stoibe[1] sp. nov.

(Plate 6, fig. 2)

Rays 5, but general form nearly pentagonal. R = 23 mm., r = 18-19 mm., R = 1.25r. Aboral surface swollen, the vertical diameter being about 14 mm. Paxillae numerous with slender stalks about equal to the many (8-10) spines; the whole surface is thus rather finely rough, the membrane with small spiracula about as many as paxillar spines. Osculum large but the numerous spines around it form a continuous series and are not arranged in valvelike groups. Disk margin barely formed by the tips of the actinolateral spines. The latter are very slender; 6-9 are the longest. Adambulacral spines 6 or 7 in addition to the actinolateral, very slender and somewhat pointed, increasing in length outwardly and united by a delicate membrane. Oral spines 5 on margin of each plate, apparently not united by a membrane, innermost very long, wide at base but tapering rather quickly to a slender tip; second similar but much smaller; outer 3 diminishing notably in size. Epioral spine very large; basal part, white and cylindrical; distal portion becoming glassy and sharply triangular (in section). Color, light cream-color.

Holotype: M. C. Z. No. 3824, from St. 3469, off Bahia de Matanzas, 425 fms. This is the gretaest depth at which the *Atlantis* took Pteraster but it is not significantly greater than that at which the other species were taken. There is no doubt however that this specimen is unique among the 21 Pterasters secured and it is quite unlike any other known species. In my key, already referred to, it runs down to either *obesus* or *reticulatus* and in Fisher's key, to *coscinopeplus* but these are all Pacific species whose general facies is quite different from the Cuban form.

Hymenaster pellucidus

Wyville Thomson, 1873. The Depths of the Sea, p. 120.

There are 3 small Hymenasters from St. 2970, in the Windward Passage, south of Oriente Province, 1600-1800 fms. which may be referred to this northern species for the present, tho they are much too young for certain identification. They are only 20-25 mm. across and show some diversity in superficial characters. A still smaller specimen, 13 mm. across, may be mentioned here tho it is probably

(1) στοιβή = *cushion*, in reference to the resemblancee to a small pincushion.

a different species. It was taken at St. 3313, northwest of Cabo San Antonio, Pinar del Rio Province, 550 fms. — the very opposite end of Cuba. It is not impossible that all of these juvenile Hymenasters are the young of the following species but the differences are so great it seems incredible that this can be the case.

Hymenaster regalis

Verrill, 1895. Amer. Jour. Sci. (3) *49*, p. 203.

A single large Hymenaster from St. 2975, off Punta Lucrecia, Oriente Province (northern coast), 1015 fms., may properly be referred to this species, altho its condition is not all that could be desired. It is of about the same size (R = 70 mm.) and proportions as Verrill's unique type and answers fairly well to the details of his description. It is very flat and the interradial areas are thick and quite fleshy. The upper side is a very light brown but the lower surface is a livid purplish-red. The huge pedicels are brownish.

Family Brisingidae

Odinia pandina

Sladen, 1889. *Challenger* Ast., p. 598.

A few arms of an Odinia, apparently this species were brought back by the *Atlantis* in 1938 from St. 2962A in the Bahia de Cochinos, southern coast of Santa Clara Province, 215-225 fms. They are about 200-225 mm. in length, approximately the same as in Sladen's type, and correspond well to his description. Their color is a light yellow-brown with the dry pedicels bright brown.

In 1939, the *Atlantis* secured a much larger specimen, nearly entire, also in the Bahia de Cochinos, St. 3325, 30 fms. This splendid Brisingid was more than two feet across when extended and was "bright red-orange in color". It has 15 arms and the present measurements (dry) are R = 300 mm. or more, r = 17 mm.; R = 17-18r. While it differs in some details from Sladen's description, there is no reason for doubting that it belongs to his species.

Brisinga verticillata

Sladen, 1889. *Challenger* Ast., p. 604.

A single arm is all that represents this western Atlantic species in the *Atlantis* collections. It was taken at St. 3315, in the Bahia de Corrientes, Pinar del Rio Province, 350 fms. It is not entire but

includes the basal half; it is 83 mm. long, about 4 mm. wide at each end but 8 mm. wide on the swollen, basal area, which is about 30 mm. long and supported by 7 delicate arches. Identification is possible by comparison with a specimen in the M. C. Z. from 1186 fms. off the New Jersey coast.

Freyella elegans

Brisinga elegans Verrill, 1884. Amer. Jour. Sci. (3), *28*, p. 382.
Freyella elegans Sladen, 1889. *Challenger* Ast., p. 616.

A single 13-armed specimen of this sea-star was taken at St. 2970, in the Windward Passage, off southern Oriente Province, 1600-1800 fathoms. All but 2 of the arms are detached from the disk and all have the terminal portion broken off and missing. Most of the large spines on the arms are also broken or missing. In spite of the poor condition there is no reason to doubt the identity. The species is common in the western Atlantic in 1060-2021 fms.

Freyella trispinosa[1] sp. nov.

Rays 10, moderately stout; all are more or less broken and only 3 basal portions remain attached to the disk; a careful examination indicates that the arms were over 200 mm. in length, while the greatest diameter, about 12 mm. from base, is scarcely 8 mm. and this enlargement decreases very gradually distally. Disk flat, nearly circular, 25 mm. across, closely covered with minute, polygonal or minutely circular plates, each of which carries a single, erect, acute but minute spinelet (occasionally 2); these plates are largest in the interradii just above the bare, elongated-pentagonal shield (interradial plate of Fisher) which occupies most of the space between the arm bases; this shield's lower end is sharply pointed and against each side of the point rests a similar but smaller plate (upper distal end of oral plate according to Fisher). The whole arrangement looks surprisingly like the oral shield and adoral plates of an ophiuran! An odd analogy—is it a possible homology?

Arm bases covered above, at first by spiniferous plates like those of the disk; on the sides of the arm these become more and more disconnected and above the adambulacral plates there is much bare skin. Distally too (10 mm. and more beyond the disk margin) the plates become more scattered but they do not disappear altogether until 40-50 mm. out. Meanwhile however many become transversely elongated and associated to form small, narrow superficial "ribs"

(1) *trispinosa* = *provided with 3 spines*, in reference to the armature of the oral plates.

along the sides of the enlarged portion of the arm. Distally the skin is very thin and perfectly bare. Adambulacral armature for the most part of 2 long widely spaced spines, but basally there is only one spine, located on the lower margin near middle or distally; soon the second spine appears near the upper margin, usually above, but often distal to, the lower spine; at first the upper spine is distinctly smaller; far out on the arm, the lower spine decreases in size and ultimately disappears leaving the upper spine in sole possession of the field at the tip of the arm.

Oral plates not much longer than wide, so far as their visible oral portion is concerned; the two are not closely appressed as the suture is obvious, but they appear to form a pentagon somewhat longer than wide; at the distal end of each is a large spine like those on the adambulacral plates; the proximal margin is quite straight and carries 3 very characteristic spinelets; the first or innermost is short, cylindrical or thicker at tip than basally, nearly straight and erect; the second is similar but longer and is distinctly curved away from the first; the third is nearly twice as thick as the second, distinctly longer, flattened with an abruptly widened tip, and lies almost horizontally, more or less completely meeting, across the ambulacral furrow, with its fellow from the next oral angle. Color of disk pale fawn color, more nearly white along margin but becoming a very pale and dingy pink on the arms. Irregular patches of violet here and there suggest that the living animal may have been more or less violet or red-purple in life, but it is possible that these patches are artificial.

Holotype: M. C. Z. No. 3825, from St. 2969A, off Bahia de Guantanamo, Oriente Province (southern coast), 1010 fms.

This seems to be a well-marked species somewhat like *F. pennata* Sladen from Japan, as it resembles that species in the number of rays and mouth-spines, as well as in the disk plating; but the ambulacral armature is different and the oral spines are strikingly unlike those of the Japanese species.

Family Zoroasteridae

Zoroaster ackleyi

Perrier, 1881. Bull. M. C. Z., *9*, p. 6.

Along the northern coast of Central Cuba (78° 40′ – 81° 30′ W.) this seems to be a very common sea-star at depths of 200-300 fms.; it was taken 3 times at depths over 300 fms. (475-580). The 19 stations where it was secured are numbers 2980A, 2980B, 2982B, 2982C, 2983A, 2987, 2991A, 2992A, 2993, 2999, 3000, 3437, 3465, 3467, 3478, 3479, 3480, 3482 and 3483. Aside from this limited area, Zoroaster

was taken but once; a very young individual was secured at St. 2975, off Punta Lucrecia, Oriente Province, 1015 fms. In view of the locality and depth of this station one can but wonder if there is not a mistake in the label. Altogether there are 76 specimens in the collection. They range in size from R = 21 to R = 155 mm. and in color from white to yellow or to wood-brown. No field note suggests what the color in life may be.

Mammaster sigsbeei

Zoroaster sigsbeei Perrier, 1881. Bull. M. C. Z., *9*, p. 5.
Mammaster sigsbeei Perrier, 1894. *Travailleur* et *Talisman* Ech., p. 125.

This species seems to be nearly as common as the preceding for while there are but 55 specimens, they were taken at 22 stations, along the northern coast between 78° 10′ and 81° 55′ W., in 170-325 fms. At 7 stations both species occurred. A single specimen was taken outside this district and, as in the case of *ackleyi*, it was near the eastern end of the island; in this instance, the station was 3371, off Puerto Tanamo, Oriente, 295 fms. Oddly enough the stray *ackleyi* is the smallest taken of that species, but the stray *sigsbeei* is the largest, R = 158 mm. The smallest specimen of the present species has R = 17 mm. In color there is some diversity; most of the specimens are whitish or pale yellowish but the largest is a deep yellow. A number of specimens are more or less deep blackish-brown and white but it is probable that the dark color is artificial, due to local conditions where taken or to some mishap when preserved. The stations where sigsbeei was taken are 2981B, 2982B, 2982C, 2983, 2983A, 2984, 2985, 2987, 3000, 3371, 3387, 3388, 3410, 3431, 3434, 3435, 3436, 3437, 3438, 3443, 3483 and 3490.

Family Asteriidae

Pedicellaster pourtalesi

Perrier, 1881. Bull. M. C. Z., *9*, p. 7.

This little sea-star was taken but twice in 1938 but in 1939; it was found at 9 stations, tho only once was more than a single specimen secured. It is widely distributed in 185-255 fms. but apparently is not very common. It was taken several times in the Bahia de Cochinos, south side of Santa Clara Province, and several times off Caibarien, on the north side of the same province. A single specimen

was taken off the Bahia de Matanzas, 2 were secured off Puerto Tanamo, Oriente Province, and single specimens were twice taken off the western end of Cayo Romano, Camaguey.

The 12 specimens show little diversity in size for the largest has R only 24 mm. and in the smallest R = 17 mm. Most of the specimens are cream-color or dirty whitish but one from the Bahia de Cochinos has a distinctly reddish tint and one from Puerto Tanamo is yellow. The stations where Pedicellaster was taken are 2963A, 2963E, 3333, 3375, 3387, 3388, 3428, 3431, 3437, 3438 and 3483.

Coronaster briareus

Asterias briareus Verrill, 1882. Amer. Jour. Sci. (3) *23*, p. 220.
Coronaster briareus, Verrill, 1914. Harriman Exp. Starfishes, p. 49.

This very notable sea-star must be quite rare, as the *Atlantis* met with it but once. At St. 3004, off Havana, 185-205 fms., 4 specimens were taken, of which 2 are now dry and 2 are in alcohol. Each has 11 arms, or did have in life; only the smallest (R = 50-55 mm.), dry, now has them all normally attached to the disk. Few sea-stars alter so much in being dried from alcohol; the difference is so great as to be almost unbelievable. It is due of course to the very small amount of calcareous material in the living animal. The largest of the present specimens (alcoholic) has the disk 22 mm. across and the arms exceed 130 mm.; in life the arms were probably at least 150 mm. long.

Asterias crassispina[1] sp. nov.

(Plate 7)

Rays 5, short and stout, R = 25 mm.; r = 5 mm.; br = 6 mm. R = 5r but only 4 br. General character of skeleton and spinulation as in *Asterias forbesi* but all the spines are extraordinarily short and stout; abactinal spines less than 1 mm. long but more than .5 mm. thick, often distinctly capitate; marginal spines not very much bigger tho they may exceed 1 mm. in length; adambulacral spines very numerous and crowded, rather more than 1 mm. long, thick but flattened, the tip a little widened. Oral spines about 1.75 mm. long, not widened at tip. Pedicellariae fairly numerous like those of *forbesi* but even shorter and wider. Dorsal surface brownish like *forbesi* but all spines white; madreporite nearly white.

(1) *crassus = thick, fat + spina = a thorn or spine,* in reference to the extraordinary spinulation.

Holotype: M. C. Z. No. 3826, from St. 3442, off Caibarien, Santa Clara Province, 335 fms.

This single specimen of an Asterias is in such poor condition that it might be ignored or listed merely as Asterias sp. but the more it has been studied in comparison with small examples of *forbesi*, the stronger has become the conviction that it represents a hitherto unknown species and ought to be given a name. It is certainly an Asterias from a depth, as well as a locality, far outside the range of *forbesi*. There is little doubt that specimens in good condition would be readily recognized as quite distinct from the northern allied species.

OPHIUROIDEA

Tropical seas abound with brittle-stars and the those around Cuba are no exception. Sixty year ago, Mr. Lyman wrote that "more than a quarter" of the known species were from the West Indian area. Advance in our knowledge of Indo-pacific and western American forms have greatly diminished the proportion but nevertheless the ophiurans make up much more than their share of any West Indian collection of echinoderms. In the *Atlantis* collection, there are 2847 specimens representing 74 species of which 9 are new to science and 3 others are new to the West Indies. Most are represented by good series but of 14 there is but one specimen of each. Fortunately 12 of these were previously known and 11 are represented in the M. C. Z. collection. Only one of the new forms necessitated a new genus but it has been necessary to establish a new genus for a group left nameless by an earlier writer, after being carefully and wisely segregated. Perhaps the most surprising feature of the collection is the almost complete absence of the ubiquitous family *Amphiuridae*: the *Blake* took 20 species, the *Atlantis* procured but 2.

Family OPHIOMYXIDAE

Ophiomyxa brevicauda

Verrill, 1899. Bull. Univ. Iowa, Lab. Nat. Hist., *1*, no. 6, p. 66.

This brittle-star was not taken in 1938 but in 1939, 5 specimens were secured, one excellent small adult, light reddish brown in color (dry) from Sts. 3347-3350, inside Cabo Cruz, Oriente Province, 11.5-13 fms., and 4 adults in rather poor condition without a local-

ity label. They are light grayish-brown (dried) and the disk skin is badly ruptured in each one. The largest has the disk about 13 mm. in diameter, as in Verrill's type, but the arms are 65-70 mm. instead of 45. In all of the *Atlantis* specimens the arms are about 5 times the disk-diameter, so that the name *brevicauda* is not specially appropriate.

Ophiomyxa tumida

Lyman, 1883. Bull. M. C. Z., *10*, p. 272.

This species would seem to be a fairly common one, as the *Atlantis* met with it both years, at 18 stations, bringing back 24 specimens, ranging from 6 to 21 mm. in disk diameter. Most of the dry specimens are light yellow-brown, with disk a darker brown above, and the lower surface more or less nearly white especially the oral frame. One specimen is nearly white all over (probably bleached) and another is dingy gray-brown. The finest specimen has retained much of the colors of life; the arms are orange-red above and the disk is light brown; the whole lower surface is very light, yellowish white on the oral frame but quite yellow on the distal part of the arms. Most of the material was taken on the northern coast of central Cuba, between 78° 41′ and 81° 29′ W., in 145-260 fms. but 3 specimens were secured off Puerto Tanamo, Oriente Province, in 230-300 fms. and 4 came from the Bahia de Cochinos, south side of Santa Clara Province, in 260-320 fms. The station numbers are 2980A, 2982E, 2999, 3000, 3323, 3324, 3328, 3374, 3375, 3376, 3392, 3393, 3394, 3414, 3421, 3436, 3478 and 3480. At St. 3392, 5 specimens were taken, at St. 3323, 2, and at St. 3394, 2; elsewhere only single specimens were secured.

Ophiogeron granulatus

Ophiosciasma granulatum Lyman, 1883. Bull. M. C. Z., *10*, p. 269.
Ophiogeron supinus Lyman, 1883. Bull. M. C. Z., *10*, p. 269.

The *Atlantis* was so fortunate as to secure a series of 45 specimens of this misunderstood brittle-star. Nearly all are adults in poor condition, with the disk-diameter more than 15 mm. but one has a smaller disk and permits a better comparison with Lyman's types of *Ophiosciasma granulatum* in which the disk is only 6 or 10 mm. across. The

larger of these types has been decalcified and dried (probably by accident) but the smaller is in fair condition and it seems clear that it is a young example of the larger form Lyman called *Ophiogeron supinus*. Obviously the earlier name (page precedence only!) must be retained and *supinus* treated as a synonym.

The *Atlantis* material was taken in several widely separated localities; western part of northwestern Providence Channel, Bahamas, 285 fms. (St. 2950); Bahia de Cochinos, southern coast of Santa Clara Province, 290-320 fms. (Sts. 3323, 3324); off Caibarien, northern coast of Santa Clara, 265-295 fms. (Sts. 3438, 3439); off Bahia de Matanzas, 285 fms. (St. 3483); and northwest of Puerto Cayo Moa, Oriente Province, 625 fms. (St. 3366). The largest is a very well preserved individual, 21 mm. across the disk (dry) with arms 80-85 mm. long from St. 3483. The smallest is a poorly preserved youngster only 5 mm. across the dry disk, with arms about 18-20 mm. long; this is the specimen from St. 3366, in 625 fms. It is too young to permit positive identification but there is little doubt it is the young of *granulatus*. The alcoholic specimens are pale yellow or nearly white with the tips of the tube-feet brown-orange; dried specimens are dull yellow or brownish or more or less nearly white; the disk is usually darker than the arms. The dried tube-feet are brownish with the tips a little darker or in some cases abruptly dark brown. The conspicuous membranes along the sides of the arms, supported by the arm-spines, indicate that this brittle-star swims freely rather than creeps.

Ophiophrixus quadrispinosus

Ophiobyrsella quadrispinosa Koehler, 1914. Bull. 84 U. S. Nat. Mus., p. 125.
Ophiophrixus quadrispinosus H. L. Clark, 1915. Mem. M. C. Z., *25*, p. 172.

Only a single specimen of this rare and notable species was secured. It is about 15 mm. across the disk with arms about 75 mm. long. The color (dry) is rather bright brownish-yellow, the disk distinctly darker. The station where this individual was taken is No. 2999, off Bahia de Matanzas, 145-230 fms. It seems strange that in all the prior and subsequent dredging in the neighborhood of Matanzas no other specimen was secured. The numerous serrate arm-spines and the armature of the radial shields make it a conspicuous brittle-star.

Ophioscolex tropicus

Lyman, 1878. Bull. M. C. Z., *5*, p. 157.

Altho the *Blake* found this brittle-star at several stations in the Lesser Antilles, she did not secure it in Cuban seas, nor has it been hitherto reported from that region. The *Atlantis* met with it but once, securing a single specimen at St. 2987A, in Nicholas Channel, south of Cay Sal Bank, 285-300 fms. It is an adult specimen, 8 mm. across the disk with arms about 25 mm. long. The color (dry) is a very light brown.

Family Trichasteridae

Asteroschema arenosum

Lyman, 1878. Bull. M. C. Z., *5*, p. 235.

A single adult, taken at St. 2995, off Bahia Cardenas, Matanzas Province, in 370-605 fms., was the only representative of this not uncommon species, with which the *Atlantis* met in her two trips. It is 8 mm. across the disk but the arms are too much coiled to measure accurately. The color is white except where the rubbing off of granules has left a pinkish spot or area. The larger arm-spines have, as a rule, dark tips.

Asteroschema brachiatum

Lyman, 1879. Bull. M. C. Z., *6*, p. 67.

This relatively rare species was not taken in 1938 but the following year 2 specimens were secured. The smaller, 6 mm. across the disk is still attached to a bit of a gorgonian; it was taken at St. 3302, off Playa Baracoa, Havana Province, 230 fms. The color is pale reddish-brown, the arms prettily banded with numerous narrow rings of light brown. The larger specimen is 10 mm. across the disk. It is fawn-color with the brown rings on the arms more or less evident but nowhere sharply defined. This individual was taken at St. 3463, off Bahia de Matanzas, Matanzas Province, 230 fms.

Asteroschema intectum

Lyman, 1878. Bull. M. C. Z., *5*, p. 235.

This supposedly rather rare species was taken but once in 1938 but in the following year, it was found at 7 stations. The 96 specimens range in size from 5 to 12 mm. across the disk but most of them are

adults, having disks more than 8 mm. across. There is great diversity in color; some are greenish-yellow or reddish-yellow or yellowish-brown, but others are wood brown, grayish-bown or purplish-brown. The disks are definitely lighter than the arms and are often nearly white. In many specimens, especially those that are reddish-yellow or some light shade of brown, there is a definitely red longitudinal line on the upper side of the arms. This may be very conspicuous or it may be very faint; it is lacking in the alcoholic specimens and in many of those that are dried. It is apparently fugacious but it is impossible to determine now whether it is generally present in life. Nearly all of the *Atlantis* material was collected off the Bay of Matanzas, Matanzas Province, in 175-240 fms. but the 2 specimens taken in 1938 were from off Punta Alegre, Camaguey Province, 220-225 fms., and one fine adult was secured in 1939 at Playa Baracoa, Havana Province, 260 fms. The station numbers are 2980B, 3303, 3465, 3466, 3478, 3479, 3480 and 3482.

Asteroschema laeve

Asteromorpha laevis Lyman, 1872. Ann. Sci. Nat. (5), *16*, p. 3.
Astroschema laeve Lyman, 1875. Ill. Cat. M. C. Z. No. 8, pt. 2, p. 26.

This not uncommon species was found but twice in 1938 while in 1939, a dozen specimens were taken at 9 stations. Most of these were from off Caibarien, or Bahia de Matanzas, in 175-295 fms. but 2 specimens are from Playa Baracoa, Havana Province, 230-260 fms., one is from off Punta Alegre, 195 fms. and there is a very fine pair from the Bahia de Cochinos, southern coast of Santa Clara Province, 205 fms. These are large adults, 8 mm. in disk diameter, light cream color with faint brown markings on the basal part of the arms; distally the markings are in the form of light purplish-brown rings, irregularly placed and often faint. The smallest specimen taken is 4 mm. across the disk, the largest is the one mentioned above, 8 mm. across. The stations where *laeve* was taken are 2963C, 2981C, 3302, 3303, 3436, 3438, 3439, 3463, 3465, 3479 and 3482.

Asteroschema oligactes

Asterias oligactes Pallas, 1778. Nova Acta Acad. Caes. Leop., *2*, p. 239.
Asteroschema oligactes Lütken, 1856. Vid. Med., p. 116.

This, the longest and best-known species in the genus, was taken many times by the *Atlantis*, 60 specimens from a dozen stations being in the collection. The smallest specimen is 4 mm. across the disk, the

largest is 10; the latter has arms at least 250 mm. long and 3 mm. thick at the base. A specimen not quite 6 mm. across the disk is symmetrically hexamerous. In color, the range is from nearly white to grayish-blue or slate color, on the one hand and on the other, to yellow-brown. The arms are more or less distinctly banded with rust-color or some shade of brown. Naturally the darker the ground color, the less conspicuous are the markings.

Most of the specimens are from off the Bahia de Matanzas, 175-285 fms., but 11 are from the Bahia de Cochinos, southern side of Santa Clara Province, 200-265 fms., 6 are from Playa Baracoa, Havana Province, 260 fms. and one is from off Caibarien, Camaguey Province, 255 fms. The staiton numbers are 2962, 2963C, 2980B, 3303, 3326, 3436, 3465, 3467, 3479, 3480, 3482 and 3483.

Ophiocreas spinulosum

Lyman, 1883. Bull. M. C. Z., *10*, p. 281.

Not taken in 1938, this fine large Ophiocreas was secured in 1939 at 3 stations (3371, 3439, 3483) and there are 2 young specimens with no locality label. These young ones are dull pinkish in color, the interradial areas of the disk darker than the arms; one is 8 mm. across the disk, the other only 6. The largest specimen is 17 mm. across the disk and the arms are more than 550 mm. long and 5 mm. high at base. These large specimens are dark purplish-brown in color. A specimen from St. 3439 is remarkable for its light coloration; the disk is brown, the radial shields and arm-bases light brown, becoming lighter distally. The 3 known stations whence these 8 specimens of Ophiocreas came are widely separated; one is off PuertoTanamo, Oriente Province, one off Caibarien, Santa Clara, and the third off Bahia de Matanzas. They show a remarkable uniformity in depth, 285-295 fms.

Asteronyx loveni

Müller and Troschel, 1842. Syst. Ast., p. 119.

Only 8 specimens of this well known, widespread species were secured by the *Atlantis*. They come from widely scattered stations (Puerto Tanamo, Oriente; Punta Alegre, Camaguey; Bahia de Matanzas, Matanzas, and Bahia de Cochinos, southern coast of Santa Clara), at depths of 145-295 fms. All are young or half-grown, the

disk diameters ranging from 7 to 14 mm. The largest is dull pink, lighter on radial shields, darker on iterradial areas. The others are the usual pale yellowish with interradial disk-areas dark brown. One of the specimens from off Punta Alegre is notable for the very numerous short teeth and teeth-papillae, but this is apparently only an individual peculiarity. The smallest specimen is perfectly tetramerous. The stations where Asteronyx was taken are numbers 2963E, 2980B, 2999, 3371 and 3478.

Astrodia tenuispina

Astronyx tenuispina Verrill, 1884. Amer. Jour. Sci. (3), *28*, p. 219.

Astrodia tennuispina Verrill, 1899. Bull. Univ. Iowa, Lab. Nat. Hist., *1*, no. 6, p. 74. (Error in spelling of specific name.)

In 1938, in Nicholas Channel, south of Cay Sal Bank, at 280-300 fms. (Sts. 2987 and 2987A), the *Atlantis* secured 5 specimens of this species, previously known from off the eastern coast of the United States in much deeper water (1362-2033 fms.) It is apparently specimens are 6-12 mm. across the disk. Those from 2987 are very pale brownish-white but the one from 2987A is definitely pink.

Family Gorgonocephalidae

Astrogomphus vallatus

Lyman, 1869. Bull. M. C. Z., *1*, p. 350.

This pretty ophiuran is represented by 23 specimens from 7 stations off Punta Alegre, Camaguey Province, 205-230 fms., off Caibarien, Santa Clara Province, 265 fms., off Bahia de Matanzas, Matanzas Province, 200-240 fms., and off Playa Baracoa, Havana Province, 230-260 fms. The station numbers are 2980B, 2982B, 3302, 3303, 3438, 3478 and 3480. The specimens range in size from 5 to 15 mm. across the disk and in color from pale yellow to dull gray; the handsomest have the radial shields and disk spinules cream color, the rest of the disk light lavender-gray, and the arms cream-color with numerous, closely placed, narrow bands of the light lavender-gray. These ophiurans are always associated with other invertebrates, usually gorgonian corals, but often stalked crinoids or long-spined sea-urchins, notably *Poriocidaris nuttingii*.

Asteroporpa pulchra

H. L. Clark, 1915. Mem. M. C. Z., *25*, p. 182.

The *Atlantis* has secured a dozen specimens of this fine species known hitherto only from the 3 types taken off Barbados by the *Blake*. The largest of the types was only 8 mm. across the disk but most of the Cuban series are larger than this, the largest being 24 mm. across, with arms 140 mm. to the first fork, 25 more to the second and (estimated only, as they are too closely coiled for measurement) about 80 or more to the very delicate tips. The smallest specimen is only 4 mm. across the disk but comparison with the smallest of the types, which is also 4 mm. across, indicates that this specimen is not normal but has had a disk injury which has led to a considerable contraction ;the arms are much stouter than in the small type.

The *Atlantis* specimens reveal two types of coloration, but there is no sharp line of division between them. At one extreme is a very large individual, distinctly yellow-brown and at the other is an equally large specimen, light and dark gray with no trace of yellow. Of the other specimens, 4 are inclined towards yellow-brown, the others show no yellowish tinge. There is no relation between the color and the location where taken for all but one come from off the Bahia de Matanzas, in 175-240 fms. The one exception is from Playa Baracoa, Havana Province, in 260 fms. All of the specimens were associated with gorgonians or pentacrinids. The station numbers are 3303, 3465, 3478, 3480 and 3482.

Astrospartus mucronatus

Astrophyton mucronatum Lyman, 1869. Bull. M. C. Z., *1*, p. 348.
Astrospartus mucronatus Döderlein, 1911. Japan Euryalae, p. 28.

This common "basket-fish" was taken at half a dozen stations but only 9 specimens were brought home. They were found only off Punta Alegre, Camaguey Province, in 205-260 fms. and off Bahia de Matanzas, 145-285 fms. The stations numbers are 2980A, 2980B, 2982B, 2999, 3465 and 3483. The largest is 53 mm. across the disk, while the smallest is only 7 mm. This little one and another, 14 mm. across the disk, are cream-colored, the areas of the disk not covered by the radial shields being slightly gray. The large specimens are yellower, browner or grayer, becoming darker evidently as they increase in size.

Family Hemieuryalidae

Ophiochondrus gracilis

Verrill, 1899. Bull. Univ. Iowa, Lab. Nat. Hist., *1*, no. 6, p. 64.

The *Atlantis* took at St. 3302, Playa Baracoa, Havana Province, 230 fms., a single specimen of this species which has hitherto been known only from the unique holotype. This specimen of Verrill's lacked the disk but the disk-scar was 3 mm. across. The arms were more than 20 mm. long. The distinctive characters of the species were noted as the long slender arms, the presence of 8 arms spines, the character of the mouth parts, the character of the upper and under arm-plates, the tentacle-scales, and the elongated upper arm-spines on the basal arm-segments. In all these details the present specimen agrees well with Verrill's description, tho it is somewhat smaller apparently, as the disk is only 2 mm. across. Fortunately the disk is present and the description of the species can therefore now be completed. The relatively large, triangular radial shields cover 5 lobes of the disk between which are deep sulci, much as in *Ophiocamax hystrix;* radial shields in contact distally but their inner ends are separated by several very narrow plates each of which bears a relatively very large thorny spinule; similar spinules are borne on plates at the center of the disk, which they conceal; the distal margin of each radial lobe is notched over the arm and each half is somewhat swollen and covered by relatively large plates, some, at least, of which carry thorny spinules like those of the disk. As a whole therefore the disk is conspicuously swollen, ten-lobed marginally and markedly thorny.

This is an interesting and well-marked species and it is greatly to be regretted that more specimens were not secured. If however it does not grow to a larger size, it is not strange that it is not frequently taken for it would not ordinarily be noticed in working over the contents of a rich haul of the dredge. Only a collector intent on small ophiurans would be at all likely to notice so insignificant a creature.

Ophiochondrella squamosa

Ophiochondrus squamosus Lyman, 1883. Bull. M. C. Z., *10*, p. 275.
Ophiochondrella squamosa Verrill, 1899. Trans. Conn. Acad., *10*, p. 356.

This is also a rare species for apparently the holotype in the M. C. Z. is the only known specimen. It is therefore very fortunate

that the *Atlantis* secured 2 specimens at St. 3305, off Playa Baracoa, Havana Province, 330 fms. One of the specimens is 7 mm. across the disk, thus a trifle larger than Lyman's specimen, while the other is but 4.5 mm. They agree in all essentials with the holotype but are slightly darker in color; the larger specimen is a light yellow-brown, the smaller somewhat lighter. The character of the disk covering and that of the under arm-plates amply justify Verrill's genus.

Sigsbeia murrhina

Lyman, 1878. Bull. M. C. Z., *5*, p. 234.

It is very curious that this common West Indian species (there are 243 specimens in the M. C. Z.) was taken only at one place (Sts. 3302 and 3303, Playa Baracoa, Havana Province, 230-260 fms.) by the *Atlantis*. There are 16 specimens, ranging from 8 to 12 mm. across the disk. All are light colored, creamy white with a light brown or grayish disk and more or less evident, rather broad and indefinite light brown rings on the arms, distally.

Family Ophiacanthidae

Ophiacantha echinulata

Lyman, 1878. Bull. M. C. Z., *5*, p. 229.

A very fine series of 33 specimens of this well-marked species, ranging in disk diameter from 5 to 16 mm., was secured at 18 different stations, 17 of which are along the northern coast of Cuba from 75° 21′ – 82° 37′ W., in deep water, 300-910 fms. The remaining station is on the southern coast, off Guantanamo in 1070 fms. where 2 typical adults were taken. The station numbers are 2987C, 2989, 2990A, 2991, 2996, 3305, 3306, 3355, 3377, 3379, 3380, 3446, 3447, 3448, 3468, 3469, 3475 and 3485.

Ophiacantha hirsuta

Lyman, 1875. Illus. Cat. M. C. Z., No. 8, pt. 2, p. 12.

Only 7 specimens of this common species were brought back by the *Atlantis*. All are adults, 12-17 mm. across the disk. They were taken off the Bahia de Matanzas, in 175-240 fms. The station numbers are 3465, 3466, 3478 and 3480.

Ophiacantha mesembria

H. L. Clark, 1915. Mem. M. C. Z., *25*, p. 201.

This brittle-star was common in the *Blake* collections but the *Atlantis*, only met with it twice, once each year. In 1938, a single specimen was secured at St. 2991A, off Bahia de Santa Clara, Santa Clara Province, 475 fms. In 1939, 5 specimens were taken at St. 3305, off Playa Baracoa, Havana Province, 330 fms. The specimens from Playa Baracoa are adults 5-6 mm. across the disk but the one from Bahia de Santa Clara is only 4 mm. across.

Ophiacantha pentacrinus

Lütken, 1869. Add. ad Hist. Oph., pt. 3, p. 46.

This is another common species which the *Atlantis* rarely took. Only 3 specimens are present in the collection, 5 mm. or less across the disk, but noticeable because of the very long arm-spines on the proximal segments. They were taken at 3 small separated stations (3438, 3445, 3465) on the northern coast of Cuba, between 79° 37′ and 81° 27′ W., in 175-330 fms.

Ophiacantha scutata

Lyman, 1878. Bull. M. C. Z., *5*, p. 229.

With this common species, the *Atlantis* met frequently, for 32 specimens were taken at 23 stations. Nearly all of these stations are between 78° 10′ and 81° 27′ W., on the northern coast of central Cuba at depths of 150-300 fms., but one is in the Bahamas, northwest Providence Channel, 285 fms. and two are off Puerto Tanamo, Oriente Province, Cuba, in 285-300 fms. The station numbers are 2950, 2980A, 2981D, 2982B, 2982D, 2983, 2985, 2987, 2987A, 3374, 3376, 3387, 3410, 3411, 3435, 3436, 3437, 3438, 3439, 3445, 3468, 3482 and 3483. Most of the specimens are adults, 8-10 mm. across the disk but a very few are young, 5 mm. or less. The smallest, 4 mm. across is apparently regenerating a lost disk.

Ophiomitra valida

Lyman, 1869. Bull. M. C. Z. *1*, p. 325.

This common brittle-star was met with at 16 stations and 47 specimens are in the collection. They range in disk diameter from 2 to 15 mm. The smaller specimens are prettily variegated with brown

markings on pale gray or pale yellow or nearly white ground color but specimens more than 8 mm across the disk are generally unicolor, light or dark gray, dull yellow or pale brown. Most of the material was taken off the Bahia de Matanzas, in 145-286 fms., but others were secured off Punta Alegre, Camaguey, and Caibarien, Santa Clara, in 220-295 fms. and off Playa Baracoa, Havana Province, in 230-260 fms. A single large adult, quite yellow as dried, was taken in the Bahia de Cochinos on the southern side of Santa Clara Province in 265 fms. The station numbers are 2980B, 2999, 3302, 3303, 3326, 3438, 3439, 3463, 3465, 3466, 3467, 3478, 3479, 3480, 3482 and 3483.

Ophioplinthaca dipsacos

Ophiomitra dipsacos Lyman, 1878. Bull. M. C. Z. *5*, p. 155.
Ophioplinthaca dipsacos Verrill, 1899. Trans. Conn. Acad., *10*, p. 351.

This apparently rare species, discovered by the *Challenger* but not taken by the *Blake*, seems to be fairly common in deep water (330-875 fms.) along the northern coast of Cuba from Baracoa, Oriente Province, to Playa Baracoa, Havana Province. Most of the specimens are from off Bahia Matanzas in 425 fms. There are 8 very small specimens, 2-4 mm. across the disk and 39 specimens, 5-11 mm. across. The arms of the larger specimens are usually more or less broken but when complete they are 8 times the disk diameter or more. Lyman's material did not permit any statement on this point and Verrill apparently did not meet with this species in the material he studied.

In a "supplementary list" of West Indian ophiurans in the collection of the U. S. National Museum, identified by Mr. Lyman (see Koehler, 1914, p. 158) this species is given as having been taken by the *Albatross* on the western edge of Arrowsmith Bank between Cuba and Yucatan in 399 fms. but there is no hint as to the number or size of the specimens.

The *Atlantis* specimens have the disk pale gray and the arms white or pale yellowish. The stations where they were taken are 2995, 3305, 3306, 3357, 3446, 3459, 3469 and 3470.

Ophiocamax fasciculata

Lyman, 1883. Bull. M. C. Z., *10*, p. 265.

This seems to be a very common brittle-star along the northern coast of Santa Clara and Matanzas Provinces, from the western end of Camaguey to the Bahia de Matanzas, in 195-535 fms. There are

255 specimens in the *Atlantis* collection from this area and there are but 2 others — both from the southern coast of the island, one from the Bahia de Corrientes, 350 fms., and one from the Bahia de Cochinos, 150-170 fms. In disk diameter the 257 specimens range from 6 to 22 mm. Most of them are quite white but a few are more or less yellow. The 22 stations where this material was taken are 2963B, 2982C, 2983A, 2985, 2987, 2987A, 2987C, 2987D, 2987E, 3315, 3434, 3439, 3443, 3444, 3445, 3446, 3447, 3448, 3449, 3450, 3468 and 3487. One of the specimens from St. 3448 is perfectly tetramerous, with the disk about 12 mm. square.

Ophiocamax hystrix

Lyman, 1878. Bull. M. C. Z., *5*, p. 232.

This species is quite as common as the preceding and even more widespread for the *Atlantis* took it, in 145-380 fms., at the following 32 stations: 2963A, 2980A, 2980B, 2981C, 2982B, 2982C, 2982D, 2983, 2999, 3303, 3319, 3333, 3371, 3389, 3408, 3427, 3428, 3430, 3432, 3435, 3436, 3437, 3438, 3439, 3448, 3465, 3466, 3478, 3479, 3480, 3482 and 3483. There are altogether 147 specimens which range in disk-diameter from 5 to 20 mm. It will be noticed that while most of these stations are in the same area where *fasciculata* was common, the two species were actually taken together at only 3 stations. The average depth is somewhat less for *hystrix*.

Ophioprium cervicorne

Ophiacantha cervicornis Lyman, 1883. Bull. M. C. Z., *10*, p. 257.
Ophioprium cervicorne H. L. Clark, 1915. Mem. M. C. Z., *25*, p. 215.

This little-known species was taken by the *Atlantis* at 7 stations (numbers 2961, 3328, 3371, 3386, 3388, 3408 and 3436) but all of the 12 specimens lack the disk covering more or less completely and are damaged in other ways. It is obviously a more or less fragile species and complete specimens are apparently very difficult to procure tho the depth at which it occurs is not very great. The present material does not permit any definite answer to the question whether *permixtum* Koehler is identical with Lyman's species. The *Atlantis* material comes from the Bahia de Cochinos on the southern coast of Santa Clara Province, 250-275 fms. and from the northern coasts of Oriente and Camaguey Provinces and off Caibarien, Santa Clara, in 200-295 fms. Oddly enough no specimens were secured west

of Caibarien, where other Ophiacanthids were most abundant. The specimens secured were all adults, 9-15 mm. across the disk, except 5 young ones from St. 3436, which are only about 6 mm. in disk diameter. In these small specimens the oral shields are as long as wide, very different from the adults, and it is quite possible they represent a distinct species.

Ophiotreta lineolata

Ophiacantha lineolata Lyman, 1883. Bull. M. C. Z., *10*, p. 258.
Ophiotreta lineolata Verrill, 1899. Bull. Univ. Iowa, n. s. *1*, No. 6, p. 40.

This large and showy brittle-star was occasionally taken along the northen coast of Cuba between Caibarien, Santa Clara, and Playa Baracoa, Havana Province, in 190-285 fms. The 34 specimens brought home are nearly all adults, 18-12 mm. across the disk but there are a few only 8-10 mm. acros. The disk is prettily spotted and blotched with dark brown, and brown spots and markings often occur on the arms at least basally. The arms are evidently very easily broken for a large proportion are more or less regenerated; in one small specimen with 5 nearly complete arms, 4 are more or less regenerated, giving the false impression of a disk and 4 arms being regenerated from the base of a single large arm, like the "comet-forms" of some sea-stars. The stations where *lineolata* was taken are numbers 2980B, 2982B, 3302, 3303, 3438, 3479, 3482 and 3483.

Ophiotreta mixta

Ophiochaeta (?) *mixta* Lyman, 1878. Bull. M. C. Z., *5*, p. 222.
Ophiotreta mixta H. L. Clark, 1915. Mem. M. C. Z., *25*, p. 216.

A single small specimen of this species 5 mm. across the disk was taken in 1939 at St. 3320, in the Bahia de Cochinos, southern coast of Santa Clara Province, at 185 fms. As the type material (9 specimens) came from off Havana, it is odd that no specimens were secured by the *Atlantis* on the northern coast of Cuba.

Ophiotreta sertata

Ophiomitra sertata Lyman, 1869. Bull. M. C. Z., *1*, p. 326.
Ophiotreta sertata Verrill, 1899. Bull. Univ. Iowa, n. s. *1*, No. 6, p. 40.

The *Atlantis* met with this ophiuran on both her voyages but only secured 7 specimens, all more or less badly damaged. They

range from 8 to 13 mm. in disk-diameter. They were taken at Sts. 2982A, 2982B, 2984, 3435 and 3436 near long. 89° on the northern coast of Cuba, in 205-255 fms.

Ophioconis miliaria

Lyman, 1878. Bull. M. C. Z., *5*, p. 221.

A single specimen of what seems to be an Ophioconis was taken in 1938 at St. 2990A, off Puerto Sagua la Grande, Santa Clara Province, 415 fms. It is very badly damaged; the disk is largely missing and the arm-spines are much broken or completely rubbed off, but it is almost certainly an Ophioconis and hence is worthy of record. There are obvious differences between the arm-spines and arm-plates of this specimen and those of the holotype of *miliaria,* but in these details the *Atlantis* specimen is not unlike some of the paratypes. It may therefore be referred to that species for the present. The disk (now wrecked) was about 5 mm. across, the very slender arms about 30 mm. long.

Family Amphiuridae

Amphiura otteri

Ljungman, 1872. Öfv. Kongl. Vet.-Akad. Förh., *28*, p. 631.

Altho the *Atlantis* met with this widely distributed Atlantic species during both cruises, only 8 specimens and some arm-fragments were brought home and only half a dozen stations (2960, 2990, 3332, 3333, 3365 and 3446) provided this material. Half these stations were in the Bahia de Cochinos, 175-270 fms. and the others were at widely separated spots on the northern coast of Cuba, between 75° and 80° W., in deeper water, 360-600 fms. All the specimens are of small size, the largest only 7 mm. across.

Amphitarsus[1] gen. nov.

Disk covered with a coat of spherical granules, not crowded but concealing more or less fully the underlying delicate scales; radial shields long and narrow, nearly parallel and fully exposed. Oral papillae somewhat irregular in number, form and position but the

(1) ἀμφί, the first two syllables of many genera in this family + ταρσός = "the flat of the wing, then generally, a wing", in reference to the wing-like genital plates.

distal oral pores are surrounded by 3 or 4, large flat, more or less circular papillae. Tentacle scales outside disk, single, very large, nearly circular; on basal segments there are 1-3 conspicuous supplementary scales. Genital plates large, flattened, wing-like, fused with the basal arm-plates (usually 4) above the lowest arm-spine (or the lower two on the fourth segment). Genital scale also somewhat conspicuous. Teeth wide, rounded or somewhat bluntly triangular.

Genotype: *Amphitarsus mirabilis* sp. nov.

This remarkable amphiurid is an aberrant member of the family for its disk covering is like that of the Ophioleucidae while the mouth parts are more like an Amphiuran. The conspicuous wing-like genital plates, fused more or less with the basal arm-segments, are quite unique and completely distinctive.

Amphitarsus mirabilis[1] sp. nov.

(Plate 8)

Disk, 6 mm. in diameter, the 5 arms 50-60 mm. long. Disk flat, more or less pentagonal, or decagonal with very short, radial sides alternating with much longer, somewhat concave interradial sides; it is covered with a coat of very fine granules which (except under a high magnification) conceal the underlying thin scales. Radial shields small and narrow in rather closely appressed pairs, hardly a millimeter long, the width of the pair scarcely half its length.

Upper arm-plates rounded pentagonal, with a short straight proximal side, somewhat longer proximo-lateral margins, and the distal sides forming a wide, convex margin; the width, at this margin, is equal to or exceeds the length of the plate; the plates are thin and rather ill-defined but seem to be in contact with each other.

Oral shields rounded pentagonal, slightly swollen; the madreporite, a little the largest, about as long as wide; the others a trifle wider than long. Adoral plates long and narrow, slightly widened proximally where they meet, much widened distally, with the radial margin raised and rounded, so it resembles a distal oral papilla. First under arm-plate much longer than wide with its lateral margins raised up into a nearly vertical, thick wall guarding the distal oral tentacle. Following plates rather ill-defined, more or less pentagonal with rounded corners and concave lateral margins; at

(1) *mirabilis* = *wonderful*, of obvious significance.

first length and breadth are about equal but soon the length is greater and distally it is double the width; the plates are in contact with each other throughout. Oral papillae in two groups; at the inner end of the jaw there are, typically, 2 short, somewhat swollen papillae on each side, the innermost forming the pair characteristic of Amphiura, Amphiodia, et al; but on most of the jaws 2 of the papillae have fused laterally into a single wide papilla, and it may be either the first and second, or the second and third which thus fuse; consequently no two of the jaws look exactly alike; at the distal end of the oral slit is a second group of papillae guarding the big oral tentacles, 3 papillae for each tentacle; these papillae are flat, more or less elliptical or circular, and stand erect beside or proximal to the tentacle. Teeth wide, thick, bluntly triangular with rounded tip.

Genital slit conspicuous with a well developed genital scale on the outer side and a still more conspicuous genital plate on the inner margin; this plate appears to be fused with the 4 basal side arm-plates forming a conspicuous vertical thin-edged wall on the radial side of the slit. Interbrachial areas densely covered with minute spinules or pointed granules. Side arm-plates well-developed but not meeting either above or below; each carries a crowded series of 9 slender, acuminate, rather fragile spines, the lowest, longest and exceeding the segment, the uppermost shortest, less than the segment. On the basal 5 or 6 segments, the spines are markedly reduced in number and size. Tentacle-scale single, very large and nearly circular; on the segments within the disk, there are supplementary scales, especially on the first two or three; one of these scales is borne on the side arm-plate and 1-3 smaller ones on the under arm-plate. Color (dry) white or whitish; the disk has a slight grayish tinge, the arms tend more to yellowish.

Holotype, M. C. Z. No. 6232, from St. 3402, off Cayo Coco, Camaguey Province, 230 fms.

There are 2 paratypes of this remarkable brittle-star, one with disk 5 mm. across and all arms broken; the other with a slightly smaller disk and arms more than 40 mm. long. The former is from St. 3332, in the Bahia de Cochinos, southern coast of Santa Clara Province, 175-225 fms. The smaller specimen is from St. 3422, off Caibarien, at the eastern end of the northern coast of Santa Clara Province, in 235 fms. The paratypes agree very closely with the larger one described and confirm the opinion that this is a new and very distinct generic form, whose relationships are obscure.

Family Ophiotrichidae

Ophiothrix angulata

Ophiura angulata Say, 1825. Jour. Acad. Nat. Sci. Phila., *5*, p. 145.
Ophiothrix angulata Ayres, 1852. Proc. Boston Soc. Nat. Hist., *4*, p. 249.

This very common species is represented by 30 specimens taken "near shore — on a sponge" in Bahia Nipe, Oriente Province. There is some diversity of color but for the most part the specimens are typical *angulata*. They range in disk-diameter from 4 to 10 mm.

Placophiothrix suensonii

Ophiothrix suensonii Lütken, 1856. Vid. Med., p. 16.

This handsome brittle-star seems to have been an elusive species for it was not taken in 1938 and in 1939 at only two stations (3320 and 3347-50). Of course it is essentially a shallow-water species and most of the *Atlantis* stations were probably too deep for it. In the Bahia de Cochinos it was taken once at 185 fms. but the locality inside Cabo Cruz, Oriente Province was at only 11.5-13 fms. The 3 Bahia de Cochinos specimens are badly broken adults, 11-13 mm. across the disk, cream-white with deep, dull red lines between the radial shields and continued far out on the upper side of the arms. The single specimen from Cabo Cruz is 10 mm. across disk, quite unbroken, a delicate gray suffused with red, a black line between the radial shields extending to arm-tips, and the numerous thin, elongated, glassy arm-spines beautifully annulated with black.

Family Ophiochitonidae

Ophiochiton grandis

Verrill, 1884. Amer. Jour. Sci. (3) *28*, p. 324.

There are 4 large Ophiochitons in the collection which may I think, be representatives of this little known species. Verrill gave no figures and his description fails to stress any really diagnostic features. Koehler (1914), altho he had 2 specimens to examine, gives no data whatever. It is a question therefore whether the Cuban specimens are really identical with the northern form and comparison with an Ophiochiton 15 mm. across the disk (M. C. Z. no. 5765) taken in 980 fathoms off New Jersey, and supposed to be *grandis*, leads to a suspicion that the Cuban specimens really represent

an undescribed species. The smallest is 19 mm., and a second is 22 mm., across the disk; the latter has arms more than 175 mm. long; it was taken at St. 2987A which is west of Caibarien on the northern Santa Clara coast, in 285-300 fms. The larger specimens are 25 mm. across the disk; the arms are all broken but were apparently not 175 mm. long. One of these and the smallest specimen were taken at St. 3459, off the western end of the Santa Clara coast, in 500 fms. The other big one is from St. 3445, in the same vicinity but in shallower water, 330 fms. This specimen is badly damaged but it is apparently the same species as the other two. Its disk is pale olive, the upper arm-plates grayish, the lower surface more nearly white. The other 3 specimens are light fawn-color above and whitish or brownish-white beneath. This notable Ophiochiton has been known hitherto only from the latitude of Cape Canaveral, Florida, northward, in 347-980 fms. Its occurrence in Cuban waters at a lesser depth and in warmer water than further north would hardly have been expected. More material is necessary before the identification of the Cuban specimens as *grandis* can be accepted.

Ophioplax pardalis[1] sp. nov.

(Plate 9, fig. 2)

Disk, 10 mm. in diameter. Arms 5, about 75 mm. long. Disk flat, rounded pentagonal, closely covered with small granules. Radial shields naked, nearly 2 mm. long, the width about half as much, parallel but separated by at least a millimeter of the granular disk surface. Upper arm plates rounded quadrangular, the proximal margin shorter than the distal which, at the base of the arm, is equal to twice the length of the plates; distally the plates increase rapidly in length and become much longer than wide; at the tip of the arm they are rounded triangular, with a markedly convex distal margin and are well separated from each other.

Interbrachial areas below closely granulated like the disk. Oral shields, rounded pentagonal, longer than wide. Adoral plates long and very narrow, scarcely or not at all meeting within; at the outer end each sends down a relatively wide branch separating the oral shield from the first arm-plate. Oral papillae 5 or 6 on each jaw margin, the proximal ones small, thick and pointed, the penultimate conspicuously the widest and flattest, the outermost somewhat similar but smaller and overlapped by it. On three of the jaws there is a small median granule overlying the column of teeth, which are 5 in number, short and wide, the most exterior smallest. Genital slits long,

(1) *pardalis* = *leopard*, in reference to its striking coloration.

margined on the interradial side by flat overlapping plates which are higher than wide. (These show clearly on only 2 or 3 of the slits.)

Under arm-plates more or less quadrangular, at first wider than long but soon the length exceeds the width and the lateral margins become concave. The proximal margin is nearly straight but the much longer distal margin is markedly convex. The plates are broadly in contact with each other until far out on the arm; near the tip of the arm the side arm-plates separate them more or less. Side arm-plates notably small on basal half of arm, distally they are relatively larger; each carries 3 subequal (or lowest the longest), rather stout, pointed (but not acute) arm-spines which at first equal but soon exceed the segments, as they lie appressed to the arm. Tentacle-scale single, very large, oval and flat. Color (dry) pale gray on disk, more nearly white on arms and oral frame; disk thickly spotted with small irregular blotches of greenish-brown; upper arm-plates with distal half white, the proximal half (or most of it) brown, but distal third of arm is unmarked gray. Lower surface unmarked but the interbrachial areas are grayer than the oral frame.

Holotype, M. C. Z. No. 6233 from St. 3482, off Bahia de Matanzas, Matanzas Province, 190 fms.

Aside from the striking coloration, the coarser disk-granulation, the generally stouter structure and the big tentacle-scales distinguish this Ophioplax from the other species of the genus.

Ophioplax spinulifera[1] sp. nov.

Disk 4.5 mm. in diameter. Arms 5, very long and slender; all are broken but they were apparently 60 mm. or more in length. Disk flat, nearly circular but 5-lobed owing to sulci between the two shields of each radial pair; disk covered with numerous, minute, thin scales, many (perhaps most) of which carry one, very small, cylindrical blunt spinule; possibly some scales carry more than one. Radial shields very small, nearly parallel but somewhat divergent proximally, separated by a very distinct sulcus. Upper arm-plates broadly oval, widest anterior to middle, about as long as wide, more or less in contact. Interbrachial areas below covered with scales and spinules, like disk.

Oral shields much longer than wide, spear-head shaped but with all angles rounded; madreporite only slightly the largest. Adoral plates apparently wanting. Oral papillae 5 on a side, much as in the preceeding species; the penultimate is largest and the outermost is somewhat concealed thereby; there are none at apex of jaw nor is there a granule there. Teeth relatively big, triangular with some-

(1) *spinuliferus* = *bearing little spines,* in reference to the disk-covering.

what rounded tip which may have a slight notch at each side. Under arm-plates as in preceding species but only the first 2 or 3 basal ones are as wide as long. Side arm-plates small, each with 5 minute, slender, acute arm-spines the lowest longest and exceeding the segment; the number soon drops to 4 and distally to 3. Tentacle-scale single oval, relatively very large. Color (dry) brown, the disk with a yellowish cast, the underside of the arms more reddish; distally the arms are very light colored, grayish above, more nearly white below.

Holotype, M. C. Z. No. 6234, from St. 2982E, off Punta Alegre, Camaguey Province, 150-180 fms.. The condition of the specimen leaves much to be desired but its distinctive feature, the disk-covering and arm-spines, are clearly shown. There is a paratype from St. 3375, off Puerto Tanamo, Oriente Province, 230 fms. but it is in even worse condition than the one described. The oral frame is complete but attached to it is only one-fifth of the disk, showing a single pair of radial shields (the sulcus between them is not very conspicuous) and the associated arm, or rather about 60 mm. of it! Another arm-fragment not quite so long is also present. These fragments are all nearly or quite white. The disk-covering, the very long arms and the 5 arm-spines are the special features of this little Ophioplax.

Family Ophiocomidae

Ophiocoma echinata

Ophiura echinata Lamarck, 1816. Anim. s. Vert., *2*, p. 543.
Ophiocoma echinata L. Agassiz, 1835. Mem. Soc. Sci. Nat. Neuchatel, *1*, p. 192.

A single specimen, 18 mm. across the disk, with all the arms broken, is the only representative of this common brittle-star, in the collection. It was taken in the Ensenada de Corrientes, Pinar del Rio, presumably "along shore", as it has no station number.

Family Ophiodermatidae

Ophioderma brevispinum

Ophiura brevispina Say, 1825. Jour. Acad. Nat. Sci. Phila., *5*, p. 149.
Ophioderma brevispinum Lütken, 1859. Add. ad Hist. Oph., pt. 2, p. 86.

This is another very common shallow-water West Indian brittle-star represented in the present collection by a single small specimen, 7 mm. across the disk. It was taken "inside Cabo Cruz, Oriente Province", 11.5-13 fms. (Sts. 3347-3350).

Ophiarachnella petersi

Ophiopeza petersi Lyman, 1878. Bull. M. C. Z., *5*, p. 217.
Ophiarachnella petersi H. L. Clark, 1909. Bull. M. C. Z., *52*, p. 125.
Pectinura angulata Lyman, 1883. Bull. M. C. Z., *10*, p. 232.

The *Atlantis* took 11 specimens of this fine ophiuran off the Bahia de Matanzas, 175-190 fms. (Sts. 3465, 3482) and a single adult off Playa Baracoa, Havana Province, in 260 fms. (St. 3303). This series is of great importance for it proves that *Ophiopeza petersi* Lyman is based on a very young specimen of the same species, a very large adult of which is the type of Lyman's *Pectinura angulata*. The former name however has nearly 5 years precedence. The type of *petersi* is 9 mm. across the disk while that of *angulata* is 27 mm. It is not at all strange therefore that even so careful a worker as Mr. Lyman failed to recognize their identity. The *Atlantis* series ranges from 15 mm. to 27 in disk diameter and the smallest is very similar to the type of *petersi* in all essentials. The arms are very long, 6-8 times the disk-diameter in the larger specimens. The color (dry) of the specimens from 3303 and 3465 is ivory-white. Those from 3482 are a pale grayish-drab.

Bathypectinura lacertosa

Pectinura lacertosa Lyman, 1883. Bull. M. C. Z., *10*, p. 231.
Bathypectinura lacertosa H. L. Clark, 1909. Bull. M. C. Z., *52*, p. 129.

This large and striking ophiuran, hitherto something of a rarity, proves to be a common species in the deep water (1010-1335 fms.) off eastern Cuba (3 stations) where 72 specimens were secured. It was also taken (but only 11 specimens) further west along the northern coast at 5 stations in 295-450 fms. The station numbers are 2970, 2973, 2975, 2990A, 2991, 3305, 3370 and 3371. The specimens range from 9 to 35 mm. across the disk with the arms 3-7 times as much; in the smallest individual they are 27 mm., in the largest they exceed 200. The color, in alcohol or dry, ranges from nearly white to pale yellowish-brown or light drab.

Family Ophiolepididae

Ophiomastus secundus

Lyman, 1878. Bull. M. C. Z., *5*, p. 218.

A single small adult of this odd little ophiuran was taken at St. 3404, off Cayo Coco, Camaguey, in 215 fms.

Amphiophiura metabula

H. L. Clark, 1915. Mem. M. C. Z., *25*, p. 311.

This common West Indian species was taken by the *Atlantis* at 10 stations (2990A, 2995, 3305, 3359, 3370, 3454, 3459, 3468, 3472 and 3475) along the northern coast of Cuba between 74° 32′ and 82° 31′ W., in depths of 330-1000 fms., and at one station (3315) in the Ensenada de Corrientes, on the southeastern corner of the island in 350 fms. The 27 specimens range from 4 to 10 mm. in disk-diameter. The disk is commonly pale gray, the arms white.

Amphiophiura oedignatha

H. L. Clark, 1915. Mem. M. C. Z., *25*, p. 312.

This apparently less common species was taken at a dozen stations to the south and southwest of the Bahamas and Great Bahama Bank (Sts. 2950, 3371, 3374, 3375, 3384, 3385, 3402, 3437, 3439, 3442, 3475 and 3476) but it was not secured west of long. 81°, nor on the southern side of Cuba. Its bathymetrical range was from 230 to 400 fms. There are 32 specimens at hand ranging in disk diameter from 4.5 to 9 mm. The large primary plates on the disk and the short arms are striking characters that distinguish this species from the preceding very easily.

Ophiura acervata

Ophioglypha acervata Lyman, 1839. Bull. M. C. Z., *1*, p. 316.
Ophiura acervata Meissner, 1901. Bronn's Thierreichs, *2*, abt. 3, p. 925.

This very common species is represented by 667 specimens from 28 stations. They range in disk diameter from 1 to 10 mm. but the great majority are less than 5. These young *acervatas* swarned at certain stations, notably 2980 and 2980A, where more than half the specimens were secured. In spite of the large number of stations where it occurred, *acervata* seems to have a very restricted range on the Cuban coast. Aside from 2 stations in the Bahia de Cochinos on the southern coast of Santa Clara Province, in 185-195 fms., where 11, adults and young, were taken, all of the remaining 656 specimens come from 180-290 fms. off the northern coast of central Cuba, east and west of Punta Alegre, Camaguey, between 78° 02′ and 79° 32′ W. This seems like a curiously restricted range for so

abundant a species. The 28 stations where *acervata* occurred are numbers 2980, 2980A, 2980B, 2981, 2982B, 2982C, 3320, 3334, 3385, 3386, 3387, 3388, 3389, 3390, 3391, 3392, 3393, 3394, 3396, 3400, 3401, 3402, 3405, 3407, 3410, 3419, 3436 and 3437.

Ophiura falcifera

Ophioglypha falcifera Lyman, 1869. Bull. M. C. Z., *1*, p. 319.
Ophiura falcifera Meissner, 1901. Bronn's Thierreichs, *2*, abt. 3, p. 925.

Oddly enough, of this common ophiuran, the collection contains but 3 specimens, 7-11 mm. across the disk, taken northwest of Caibarien, Santa Clara, in 285-320 fms. The station numbers are 2987A, 3439 and 3444.

Ophiura lepida

Ophioglypha lepida Lyman, 1878. Bull. M. C. Z., *5*, p. 70.
Ophiura lepida Meissner, 1901. Bronn's Thierreich, *2*, abt. 3, p. 925.

This is a common deep-water species in the North Atlantic. It was taken by the *Atlantis* at half a dozen stations (2979, 2987A, 3338, 3345, 3359 and 3404) in 215-1075 fms. These stations are widely scattered on both the northern and southern coasts. There are 12 specimens in all, 6-11 mm. across the disk.

Homalophiura abyssorum

Ophioglypha abyssorum Lyman, 1883. Bull. M. C. Z., *10*, p. 238.
Homalophiura abyssorum H. L. Clark, 1915. Mem. M. C. Z., *25*, p. 326.

The *Atlantis* met with this deep water form once in 1938, St. 2970 in the Windward Passage, southeast of Oriente Province, 1600-1800 fathoms.) and once in 1939 (St. 3355, off Bahia de Guantanamo, Oriente, 1070 fms.) The 3 specimens are typical adults, 12-15 mm. across the disk.

Ophiomusium acuferum

Lyman, 1875. Illus. Cat. M. C. Z., No. 8, pt. 2, p. 7.

This common and widely distributed West Indian brittle-star was met with but seldom by the *Atlantis*. Only 8 specimens, 4-10 mm. in disk-diameter were taken, 4 in the Bahia de Cochinos on the southern coast of Santa Clara Province, in 185-200 fms., and 4 off the Bahia de Matanzas, on the northern coast of Matanzas Province, 175-240 fms. The station numbers are 3320, 3335, 3465 and 3478.

Ophiomusium eburneum

Lyman, 1869. Bull. M. C. Z., *1*, p. 322.

This is another common species which the *Atlantis* met with but once in 1938 but took at 9 stations the following year. The specimens are 5-12 mm. across the disk and all but one are ivory-white or yellowish. The single specimen taken in 1938 is quite pink and does not look as tho this were due to accidental staining. Except for a small specimen from the Bahia de Cochinos, 190-200 fms. and a large one from the Ensenada de Corrientes, 350 fms., all of the 17 specmens are from the northern coast of Cuba, between 79° 43′ and 81° 22′ W., in 285-405 fms. The station numbers are 2987A, 3315, 3333, 3442, 3443, 3447, 3451, 3475, 3485 and 3487.

Ophiomusium lymani

Wyville Thomson, 1873. Depths of the Sea, p. 172.

This is probably the most common and widely distributed of deep water ophiurans. There are 217 specimens in the *Atlantis* collection from the following 31 stations: 2950, 2987, 2987A, 2987C, 2990A, 2995, 3305, 3306, 3313, 3315, 3323, 3324, 3338, 3355, 3359, 3370, 3371, 3374, 3379, 3437, 3438, 3442, 3443, 3444, 3445, 3446, 3447, 3448, 3468, 3475 and 3483. These stations are scattered from end to end of Cuba and northward into the Bahamas, in depths of 265-1070 fms. The specimens range from 3.5 to 25 mm. in disk-diameter but there is no evident correlation between size and depth where taken. It is true the smallest were never taken with large adults but specimens 10 mm. across occur with those twice as big. Many of the smaller specimens have the disk elevated and the arms segmentally constricted as in *Ophiosphalma dyscritum* so that the superficial resemblance to that species is striking but a glance at the lower surface distinguishes the two at once. A specimen from St. 3323 is tetramerous but not symmetrically so. All the smaller specimens are more or less nearly white but the larger ones tend to become more or less brownish.

Ophiomusium stellatum

Verrill, 1899. Bull. Univ. Iowa, n. s. *1*, no. 6, p. 14.

This seems to be a rare species as there are none in the M. C. Z. collection and Verrill had but 2 small examples. The *Atlantis* was

so fortunate as to secure 6 specimens in 1939, ranging in disk diameter from 5 to 8 mm. The color is white with the disk tending to gray, the arms to yellow. The large marginal scale or plate in each interradius and the flattened, attenuate arms, with a marked tendency to "segmental contraction" (i. e. each segment is distinctly smaller proximally than distally) are very characteristic. Verrill says there are 3 arm-spines, but this is true only of the basal segments of the larger individuals. As a rule there are 2 well separated slender spines, the lower the longer, and they have a tendency not to lie appressed to the arm. These specimens were secured at 3 widely separated places: St. 3319, in the Bahia de Cochinos, southern coast of Santa Clara, 195-215 fms.; Sts. 3387 and 3393, off the northern coast of Camaguey Province, 222-245 fms.; and St. 3483, off the Bahia de Matanzas, 285 fms.

Ophiomusium testudo

Lyman, 1875. Illus. Cat. M. C. Z., No. 8, pt. 2, p. 8.

Only half a dozen specimens of this not uncommon species were taken by the *Atlantis*, all in 1939. They range from 5.5 to 7 mm. in disk-diameter. The color is either yellowish of some shade or a pale brown. The largest specimen has no station number; the others are from Sts. 3438, 3478 and 3482, on the northern coast between Caibarien and Bahia de Matanzas, in 190-265 fms.

Ophiomusium validum

Ljungman, 1872. Öfv. Kongl. Vet.-Akad. Förh., *28*, p. 618.

This seems to be the most abundant of the deeper water brittle-stars in Cuban seas for the *Atlantis* took it at a dozen stations in 1938 and at no fewer than 40 in 1939. But these numerous stations are readily grouped in three areas: Bahia de Cochinos, southern coast of Santa Clara Province, 155-270 fms.; Old Bahama Channel (Cayo Romano to Caibarien) 190-260 fms.; and off the Bahia de Matanzas, 145-255 fms. A single specimen is labelled "off northern coast of Cuba, 100 fms. ±" – doubtless more. There are 2 specimens from off Puerto Tanamo, 230-285 fms. but obviously *validum* is not common east of 78° W. or west of 81° 30′.

Altogether there are 221 specimens, with the disk diameter ranging from 5 to 18 mm. The stout interradial plate forming the disk margin and occupying nearly all the space between the genital scales

to the oral shield itself, on the smooth, flat oral surface makes the recognition of *validum* very easy. Most of the specimens are more or less nearly white but some are distinctly yellowish and one lot is pale gray. The stations where this Ophiomusium occurred are 2960, 2963A, 2963B, 2963C, 2981B, 2981C, 2981D, 2982A, 2982B, 2982C, 2999, 3000, 3319, 3320, 3331, 3332, 3333, 3334, 3335, 3336, 3375, 3376, 3386; 3387, 3388, 3389, 3391, 3392, 3393, 3394, 3401, 3402, 3403, 3404, 3405, 3410, 3411, 3412, 3416, 3423, 3425, 3428, 3430, 3434, 3436, 3463, 3465, 3466, 3467, 3478 and 3479; 2 lots lack station numbers.

Ophiomusium leptobrachium[1] sp. nov.

Disk 11 mm. across, convex but flattened at center; oral surface quite flat; radial shields large, about 3.5 mm. long, the distal end nearly 2 mm. wide, the inner end narrower, all angles rounded; distal half of plates broadly in contact, proximal ends separated by a large triangular scale, longer than wide. Between the shields interradially is a single large plate, about as big as one of the shields but more nearly quadrilateral, distinctly longer than wide, widest at disk margin. Remainder of disk covered by the 6 primary plates and 25-30 similar but for the most part smaller plates; the 5 largest plates are interradial and directly adjoin the long marginal plates. All the disk plates are finely shagreened.

Arms 5 relatively short and slender, approximately cylindrical; all are broken but it is doubtful if they exceeded twice the disk diameter; at base they are about 1.75 mm. thick; the broken ends are scarcely more than 1 mm.; each segment is a trifle smaller proximally than distally. At the base of the arm, crowded against the ends of the radial shields is a group of 4 small, somewhat swollen plates. Upper arm-plates only 4 or 5, the first two swollen, triangular, hardly half a millimeter wide, the following 2 or 3 very minute.

Interbrachial areas below covered by 6 plates, a large somewhat swollen, more or less pentagonal, marginal with a smaller but also swollen plate on each side of it; a large genital scale on each side of the area and a flat, pentagonal oral shield, with a sharp inner point; the sides of which are slightly notched by the genital slits, which are hardly longer than the first arm-segment. Adoral plates, much longer than wide, meeting broadly within, widest at distal ends, which abut fully against the first side arm-plates. Oral papillae 6 on a side, distalmost widest,innermost smallest, closely appressed to each other but not fused together. Under arm-plates 2, shield-shaped, longer than wide, each side made concave by the tnetacle-pore which

(1) λεπτός = *slender* + βραχίων = *arm*, in reference to the relatively slender arms.

adjoins it; each pore is covered by a thick, circular scale. There are no other plates or pores. Arm-spines 3, 2 close together, low down on the side arm-plate, and one placed a little space above them; all are small and peg-like; one of the lower pair is often missing but this may be accidental. Color (dry) pale gray, arms more nearly white.

Holotype, M. C. Z. No. 6235 from St. 3363, off Puerto Cayo Moa, Oriente Province, 830 fms. There are 2 paratypes from the same station, 6 and 8 mm. across the disk; all the arms are broken. They resemble the holotype closely in all particulars. These specimens were at first referred to *validum* but when the large series of that well-marked form was critically examined, it became obvious that they were certainly not that species, but there does not seem to be any other known Ophiomusium to which they can be referred.

Ophiomusium microporum[1] sp. nov.

Disk 6 mm. in diameter, somewhat swollen (2 mm. high), covered with the 11 primary plates, the 5 pairs of radial shields and a long, narrow interradial plate, which separates the pairs of radial shields and joins a wide plate which occupies the entire interradial margin; this plate is depressed into a broad wedge, the edge of which forms a sharp margin to the disk; the central plate and 5 radials form a conspicuous group, the primary interradials being much smaller. Radial shields as wide as long, broadly in contact, all angles rounded. The surface of the disk is not smooth but it cannot be called "shagreened"; it has more the character of chalk.

Arms 5, about 16 mm. long, flattened and a little widened at base but tapering rapidly and becoming quite moniliform distally. Upper arm-plates few and small; the first is distinctly triangular, the next is less so and the 2 or 3 others are very minute. The arm-bases and adjoining parts of the disk are somewhat obscured by dry ooze or fine sediment clinging persistently to it.

Interbrachial areas below smooth and in most of the specimens perfectly flat; in the holotype the oral surface is obviously convex. Each area is covered by the relatively huge marginal plate, already described, and a big oral shield, with a relatively large genital scale on each side; oral shields pentagonal, with the long inner sides, concave or notched by the proximal end of the genital slit. Adoral plates larger than genital scales, meeting broadly within but somewhat wider at their distal ends. Oral papillae fused into a straight, narrow blade along each jaw-margin. Under arm-plates 2, relatively

(1) μικρός = *small* + πόρος = *a pore*, in reference to the very small tentacle-pores.

large, shield-shaped, longer than wide, each side made concave by the tentacle-pore which adjoins it; each of the minute pores is about three-fourths covered by a small, thick scale. There are no other plates or pores. Arm-spines very minute and curiously distributed; on most of the side arm-plates there are 2, the upper the longer and about half as long as the segment; on many basal plates an additional spine (and sometimes 3) is present on the upper surface; no 2 of the spines are close together; when 3 are present the uppermost is about as long as the lowest; when 4, the uppermost is smallest. Color (dry) ivory-white.

Holotype, M. C. Z. No. 6236 from St. 3384, off western end of Cayo Romano, Camaguey Province, 290 fms. There are 22 paratypes, 3.25-6 mm. across the disk, which agree very closely with the one described. Most of these were taken between Cayo Romano and Caibarien in 210-290 fms., but one specimen was collected in 1938 in the western part of the N. W. Providence Channel, Bahamas, in 285 fms. and 2 were taken in 1939 in the Bahia de Cochinos, southern coast of Santa Clara Province, in 190-200 fms. The station numbers are 2950, 2982, 3333, 3384, 3385, 3387, 3388, 3436, 3437 and 3466.

This little brittle-star occurred at 5 stations with *Ophiomusium validum* and was at first supposed to be the young of that species but when young *validum*, 5-6 mm. across the disk, were found to be in all essentials like the adult, it became obvious that could not be the case. Further efforts to place them as the young of some other known species proved futile and they are thus of necessity made the basis of a new name. The species is well-marked by the huge marginal plate in each interradius, the "chalky" surface and definite arrangement of the relatively few disk-plates, the few, large plates of the oral surface, the minute tentacle-pores and the characteristic arm-spines. It cannot be confused with any known species.

Ophiomusium moniliforme[1] sp. nov.

Disk 6 mm. in diameter, somewhat swollen, covered with a coat of small, overlapping, thin scales, among which the primary plates are not evident; one of the interradial scales near the disk margin is, in 4 of the interradii, distinctly larger than its fellows and wider than long, but it does not form a marginal plate. Radial shields small, obliquely elliptical, longer than wide, completely separated by a few radial disk-plates.

(1) *monilis* = *necklace* + *forma* = *in the form of*, in reference to the beaded character of the arms.

Arms 5, about 25 mm. long, slender and attenuate, the segments smaller distally than proximately so that the basal portion of the arm (the first 12-15 segments) may properly be called moniliform; distally the segments are so elongated, their moniliform appearance fades out. Upper arm-plates very small; they continue to about the twentieth segment but only the first eight or ten are easily seen; the basal ones are rounded triangular and distinctly swollen.

Interbrachial areas below covered with numerous small plates like those of the disk. Genital slits very small, about as long as the first arm-segment beside which they lie. Oral shields very small, rounded triangular, about as long as wide. Adoral plates long and narrow, wider without than within where they meet fully. Oral papillae indistinct and thin, more or less fused to form a thin continuous edge to the side of the jaw. Under arm-plates very small, more or less triangular, continuing out to about the tenth segment, the first two are the largest and are accompanied by a small tentacle-pore on each side, which is closed by a circular tentacle-scale. Arm-spines 2 or 3 the lowest longest (about equal to one-third of the segment), cylindrical, blunt and peg-like; distally the uppermost becomes transformed into a toothed hook. Color (dry) light brown.

Holotype, M. C. Z. No. 6237 from St. 2953, in the Ensenada de Corrientes, Pinar del Rio Province, 615 fms. This specimen is unique; there is nothing like it in either the *Atlantis* collection or that of the M. C. Z. It resembles *stellatum* Verrill in the character of the disk covering and of the oral surface, but the arms are entirely different and the disk is a different shape.

OPHIOSPHALMA[1] gen. nov.

Owing to Hertz' blunder (1927, p. 102) in selecting for the type of her proposed new genus, Ophiomusa, the widely distributed and typical Ophiomusium, *lymani* Wyv. Th., it is necessary to give a new generic name to the species of Ophiomusium having 3 pairs of tentacle-pores. The genus when established by Lyman in 1869 was monotypic and the species for which it was established was named *eburneum*. In his diagnosis of the genus Lyman does not say definitely what the number of pore-pairs is but in his description of the species he emphasizes the fact that there are but two. Apparently Hertz did not realize that since the genus is monotypic, if, when more species are known, a division is proposed on the one character of

(1) *Ophio,* a common prefix for genera of brittle-stars, + **σφάλμα** (neuter) = *a false step,* in reference to the mistake which necessitates a new name.

"number of pore-pairs", the name Ophiomusium must be used for the type-species, *eburneum* and those, like it, having but 2 pairs of pores. Had she given the name Ophiomusa to those with 3 pairs, all would be well; as it is, her name is simply a synonym of Lyman's. Hence the name Ophiosphalma is here proposed for those species of Ophiomusium in the old sense, which have 3 pairs of tentacle-pores (occasionally 2 or 4 on individual arms).

Genotype: *Ophiomusium planum* Lyman

It is interesting to note that Lyman never considered the exact number of tentacle-pores as of primary importance and it is not always easy to determine from his descriptions just how many there were in the specimen he was describing. With the accumulation of material and the ever-rising number of species (more than 40 in Ophiomusium *sens. lat.*), the importance and constancy of the character has become evident and the division into 2 genera is quite justified. Further subdivision of Ophiomusium on the basis of other characters is probably desirable.

Ophiosphalma armigerum

Ophiomusium armigerum Lyman 1878. Bull. M. C. Z., *5*, p. 109.

This deep-water North Atlantic species was found in 1938 at 4 stations (2967, 2970, 2973 and 2976) but in 1939 only a single specimen was secured, at St. 3444. This individual, 15 mm. in disk-diameter, has larger radial shields and hence a smaller central area of disk scales than in typical specimens but these features may be due to its occurrence in much shallower water (320 fms.) than the others (1245-1800 fms.) It was taken in Nicholas Channel, south of Cay Sal Bank, while the 1938 material was all taken at the extreme eastern end of Cuba. The 13 specimens range in size from 8 to 22 mm. across the disk. They are more or less ivory white in color but the pair from 2967 are distinctly purplish-pink due, apparently, to accidental staining.

Ophiosphalma monoplax

Ophiomusium monoplax H. L. Clark, 1915. Mem. M. C. Z., *25*, p. 331.

This species is so easily confused with *serratum*, which was never very clearly defined, that it is interesting to find 2 specimens in the *Atlantis* collection. One, 10 mm. across the disk, was taken with

serratum at St. 3485, off Bahia de Matanzas, in 385 fms. The other, a trifle larger and with somewhat more slender arms, is from St. 3459 in Nicholas Channel off Bahia de Santa Clara, in 500 fms. No other Ophiosphalma and no Ophiomusiums were taken at that station.

Ophiosphalma serratum

Ophiomusium serratum Lyman, 1878. Bull. M. C. Z., *5*, p. 109.

Lyman described and figured this species in the *Challenger* Report on the basis of a single specimen, 10 mm. across the disk, taken near Sombrero, Virgin Islands. He never discussed it further but in his *Blake* Report listed a considerable number of stations where it was taken. There were 30 of these specimens in the M. C.Z. collection but in 1915, half were segregated under the name *monoplax* H. L. Clark. The rich collection of Ophiomusiums brought back by the Atlantis compelled a reëxamination of the *Blake* material and it was soon evident that among the 15 still listed as *stellatum*, at least 2 recognizable forms are present. Both of these are well represented in the *Atlantis* material and the one which most resembles Lyman's figures and description of his *Challenger* type is accepted as *serratum*. It must be stated however that in at least one important point his figure contradicts his description. He says the oral shield is 1.5 times as long as wide while his figure shows the shield distinctly wider than long. The figure is wrong for in all the scores of specimens examined in the *Atlantis* and *Blake* collections not one has been found with a shield wider than long. The distinctive features of *serratum* when compared with the other specimens confused with it, are the flat, smooth disk and the terete, not at all moniliform arms. The disk scales are flat and thin and overlap much. In large specimens (15 mm. across) they are numerous but in those 10 mm. (as Lyman's type) or less, the primary plates, 3 or 4 large plates in each radius and interradius, and a number of intercalated small plates of diverse size and shape, make up the covering. Lyman gives the arm-spines as 4 or 5 but in large specimens there are 7 or 8 on the basal segments. The next to the lowest is notably shorter and stouter than its fellow (tho all are very small) and the tip has 2 terminal glassy tips, one above the other, as in the following species. Lyman makes no reference to this peculiar spine but it is so small, its peculiarities are easily overlooked in a small specimen.

That portion of the *Blake* material which differs notably from the above specimens includes a specimen from off Virgin Gorda, 1097

fathoms and 3 specimens from off Havana, Cuba, 272-450 fms. These specimens are perfectly matched by a large series of 64 individuals in the *Atlantis* collection which are described beyond as *Ophiosphalma dyscritum*.

The specimens of typical *serratum* in the *Atlantis* collection are 138 in number and range from 7 to 19 mm. in disk-diameter. They are mostly from deep water (375-1800 fms.) along the northern coast or at the eastern end of Cuba but a very few came from 215-330 fms. The station numbers are 2967B, 2970, 2975, 2993, 3305, 3306, 3355, 3359, 3362, 3366, 3370, 3404, 3447, 3448, 3449, 3450 and 3485.

Ophiosphalma dyscritum[1] sp. nov.

(Plate 9, fig. 1)

Disk 10 mm. in diameter, 4 mm. high. Arms 5, 55 mm. long, 3 mm. wide at disk margin and 2 mm. high; side arm-plates depressed proximal to middle, on upper surface of arm and swollen near the distal margin on sides of arm; consequently the alternate contraction and swelling of each segment is a conspicuous feature and suggests the moniliform arms of some ophiacanthids. Basally the side arm-plates carry 6 or 7 very short, thick, pointed arm-spines, the next to the lowest, shorter and stouter than its neighbors, with 2 hyaline teeth at tip, a smaller one below the larger terminal one (visible only with high magnification, × 90); usually the lowest arm-spine is the longest, except near base of arm where the third from bottom is often the longest and stoutest. In other specimens the number of spines rises to 10, the upper ones very small; in still other cases, there are only 5 spines even on the basal segments. The longest spine is not one-third as long as the segment. Upper and under arm-plates, the 3 pairs of tentacle-pores and scales, and the mouth parts as in *serratum*, the small oral shields distinctly longer than wide. Disk scales relatively few and thick with the large radial shields and the interradial plates, in an almost semi-vertical position, the height of the disk about 40 percent of its diameter. Color more or less nearly pure white.

Holotype, M. C. Z. No. 6238 from St. 3446, Nicholas Channel, south of Cay Sal Bank, 360 fms. There are 63 paratypes ranging in disk-diameter from 3.5 to 13 mm. In specimens less than 8 mm. in diameter, the disk may not be conspicuously elevated, but on the other hand the elevation may be obvious in young individuals only 6 mm. across. In any case, the deeply constricted arm-segments and the few, small, thick disk-plates are good marks of *dyscritum*.

(1) δύσκριτος = *doubtful*, in reference to its close relationship to *serratum*.

This species was taken at many stations between Matanzas and Puerto Tanamo, on the northern coast of Cuba in 280-390 fms. It was also taken once in the western part of the northwestern Providence Channel, Bahamas, 285 fms. and once in the Bahia de Cochinos, southern coast of Santa Clara Province in 290-320 fms. It is obviously a more shallow-water form than is *serratum*. The station numbers are 2950, 2987, 2987A, 2987C, 3323, 3371, 3439, 3443, 3444, 3445, 3446, 3447 3448, 3449 and 3483.

Ophioceramis rugosa[1] sp. nov.

Disk 5 mm. in diameter, nearly circular and quite flat, covered by about 125 overlapping scales, among which the 11 primary plates can be detected tho they are not conspicuous; the scales are markedly thickened on their free margins giving the disk a characteristic, rough surface. Radial shields obliquely elliptical, about 1.25 mm. long by .70 mm. wide, in contact at the distal end but separated proximally by 2 plates, a rounded inner one overlapping the outer triangular one; inner margin of radial shield thickened, and ending in a slight knob distally where it meets its fellow. Upper arm-plates large, rounded triangular, the distal margin straight or barely concave much wider than long, somewhat swollen, not in contact with each other even at base of arm.

Interbrachial areas below covered with scales similar to those of the disk. Genital slits large, extending nearly to disk margin. Oral shields small, less than .75 mm. wide, the length about the same or a trifle less, rounded pentagonal, the distal side very short. Adoral plates large, wider without than within where they meet fully; distal end rests squarely against the side of the small quadrangular first under arm-plate. Oral papillae in 2 distinct groups: distally 2 or 3 flat, rounded erect, scale-like papillae combine with the inner pointed tentacle-scale to enclose the big oral tentacle; proximally the papillae are small and thickened, often pointed, but their number and position show great diversity; often there is one at the tip of the jaw with one on each side but there may be 2 on each side, or even 3 on one side; frequently the one at tip of jaw is missing its position being taken by the lowest tooth; in rare instances, two papillae have fused into one broad one. (Of course, all of these varied arrangements are not present in the holotype.) Teeth 3 or 4 in a column, broad and rounded, or the lowermost narrower and somewhat pointed. Under arm-plates (after the first) more or less shield-shape, the distal somewhat convex margin longer than the plate; on the basal half of the arm the plates are more or less in contact but distally they become triangular and separated. Tentacle-

(1) *rugosa* = *rough*, in reference to the character of the diks-covering.

pores rather large, protected by 2 scales, a large one on the side arm-plate and a smaller one on the under arm-plate. Side arm-plates large, meeting above and, on distal part of arm, below also; each carries a series of 3 (rarely 4) long, slender, diverging arm-spines; they are subequal or lowest is shortest and uppermost may be longest; middle one is often thickened in the basal half; they are blunt or bluntly pointed and somewhat longer than an arm-segment. Color (dry); disk pale gray, arms pale cream-color.

Holotype, M. C. Z. No. 6239 from St. 2987C, in Nicholas Channel, southeast of Cay Sal Bank, in 300-315 fms. There are 4 other specimens from the same region (Sts. 3437, 3444 and 3445) which agree well in all essentials with the holotype but the smallest, 3 mm. across the disk, is much darker colored; under high magnification however this is seen to be artificial. Specimens from deep water on the southern coast of Cuba (2 from St. 2953, Ensenada de Corrientes, Pinar del Rio Province, 615 fms. and 2 from St. 3345, off Banco Paz, south of Santa Clara Province, 690-700 fms.) appear as tho somewhat decalcified. The edges of the scales are not thickened and those in the interbrachial arcs below are especially thin. The arm-spines are pointed, prickly and often translucent. These peculiarities are not so striking in the pair from 615 fms. but they are very noticeable in those from the deeper water. They are most conspicuous in a large adult, somewhat more than 5 mm. across the disk; the disk scales are sharply defined and the arm-spines are small, acute and translucent. While these peculiarities may be due to decalcification, it seems more probable that they are due to a deficiency of calcium or perhaps of oxygen in the water at the greater depths. This species is easily distinguished from *O. albida,* the other West Indian form, by its disk-scaling and arm-spines.

Ophiozonella marmorea

Ophiozonella marmorea Lyman, 1883. Bull. M. C. Z., *10*, p. 233.
Ophiozonella marmorea Matsumoto, 1915. Proc. Acad. Nat. Sci. Phila., *67*, p. 82.

There is a single specimen of this well-marked species from St. 3438, off Caibarien, Santa Clara Province, 265 fms. It is 7 mm. across the disk with the flat arms about 21 mm. long and 2 mm. wide at base. The dry specimen is pale cream-color.

Ophiozonella nivea

Ophiozona nivea Lyman, 1875. Illus. Cat. M. C. Z. No. 8, pt. 2, p. 9.
Ophiozonella nivea Matsumoto, 1915. Proc. Acad. Nat. Sci. Phila., *67*, p. 82.

There are 130 examples of this common deep-water brittle star, for the *Atlantis* met with it at 25 stations.

Most of these stations however were along the north coast of Santa Clara (2987, 2987A, 2987C, 2989, 3423, 3443, 3444, 3445, 3446, 3447) and Matanzas (3468, 3469, 3475, 3476, 3485, 3487) provinces, in 280-535 fms. On the south coast of Santa Clara, in the Bahia de Cochinos and Golfo Cazones, in 190-425 fms., there were 5 stations (2963D, 3324, 3331, 3333, 3341). At the extreme western end of Cuba, *nivea* was taken twice in 350-550 fms. (3313, 3315) while at the other end of the island, off Puerto Tanamo, Oriente Province, in 285-300 fms. (3374, 3376), 2 small specimens were dredged, each of which is of special interest, for one is almost perfectly tetramerous, and the other is a small example of Verrill's variety *compta*. But I agree with Koehler in doubting the desirability of recognizing the variety. The specimens of *nivea* at hand show no little diversity in the degree of separation of the radial shields, tho complete separation is rare in this lot. They range in disk diameter from 3 to 13 mm. and in color (dry) from white to pale yellow, grayish or pink.

Ophiozonella tessellata

Ophiozona tessellata Lyman, 1878. Bull. M. C. Z., *5*, p. 223.
Ophiozonella tessellata Matsumoto, 1915. Proc. Acad. Nat. Sci. Phila., *67*, p. 82.

Altho the *Atlantis* found this species at 11 stations, she secured only 22 specimens. These range in disk-diameter from 6 to 9 mm. and in color from white to light yellow. Of the 11 stations, 5 were in the Bahia de Cochinos, on the southern coast of Santa Clara Province, in 180-260 fms. (2962, 2963, 2963C, 3331, 3336) while the remaining 6 stations (3464, 3465, 3466, 3467, 3478, 3479) were across the island off the Bahia de Matanzas in 175-240 fms. Obviously this Ophiozonella is much more local in its distribution than the preceding.

Ophiozonella granulifera[1] sp. nov.

(Plate 9, fig. 3)

Disk 12 mm. in diameter, slightly pentagonal, flattened and a little concave near middle, covered with numerous small scales, more

(1) *granuliferus* = *bearing small granules*, in reference to the peculiar disk-covering.

or less overlapping, among which the primary plates are not to be distinguished; the larger plates are encircled by a ring of very minute granules, while many of the smaller plates are covered with the same; these granules are of course easily rubbed off and the larger paratype has lost most of its coating; in each interradius a small, transversely elliptical, marginal plate is present. Radial shields small, broadly oval or nearly circular, well separated by radial disk plates. Upper arm-plates rather large, quadrilateral, broader distally than proximally; distal border convex; in contact for full width of proximal end; broader than long at base of arm, they rapidly become longer than broad.

Interbrachial areas below covered like the disk with more or less granuliferous scales. Genital slits large, reaching nearly to disk margin. Oral shields rounded triangular, longer than wide; all angles are broadly rounded; the shorter side is barely convex but the two longer sides are markedly concave; in two interradii a small supplementary shield lies just distal to the shield but this is not present in the larger paratype and barely indicated in the smaller one. Adoral plates short and rather small; they do not meet within but fit closely into the concave sides of the shield. Oral papillae 7 or 8 on a side; distal ones flat and scale like, the inner ones narrow and pointed; the penultimate much the largest, the ones on each side of it about equal to each other and the next inner one not much smaller. Under arm-plates at first shield-shaped and about as wide as long but rapidly becoming triangular and more and more elongate, but they keep in touch with each other until near the tip of the arm. Tentacle-scales single and circular, the first two pairs larger than the following which decrease rapidly in size and become very minute if they do not ultimately disappear. Side arm-plates large tho they do not meet either above or below until far out on the arm. Each plate carries 4 short, slender, pointed, subequal spines, scarcely half the length of the segment; they are well-spaced from each other and lie appressed to the arm; on one or two segments 5 may be present; on the basal segment and distally there are but 3. Color (dry) ivory-white or yellowish.

Holotype, M. C. Z. No. 6231 from St. 3365, north of Puerto Cayo Moa, Oriente Province, 600 fms. There is a paratype from the same station 9 mm. across the disk and with 3 arms missing. A larger paratype, 10 mm. across the disk, but badly rubbed and with one arm missing, was taken at St. 3313, at the opposite end of the island, northwest of Cabo San Antonio in 550 fms.

This is a very well-marked species of that section of Ophiozonella, having only a single tentacle-scale at each pore. The dust-like granulation of the disk, the shape of the oral shields and the 4 arm-spines are its characteristic features.

Ophiomidas dubius

Ophiozona (?) *dubia* Lyman, 1878. Bull. M. C. Z., *5*, p. 224.
Ophiomidas dubium Koehler, 1904. *Siboga* Oph., Mer prof., p. 28.

A fine adult specimen of this rarity, 5 mm. across the disk, was taken at St. 3344, southeast of Bahia de Cienfuegos, Santa Clara Province, in 1440 fms. A smaller specimen occurred ten days later at St. 3362, northwest of Baracoa, Oriente Province, in 1020 fms.

Ophiolepis elegans

Lütken, 1859. Add. ad Hist. Oph., pt. 2, p. 105.

A single specimen of this well-known littoral form, 10 mm. across the disk, was taken inside Cabo Cruz, Oriente Province, April 9, 1939, in 11.5-13 fms. (Sts. 3347-3350).

Family Ophioleucidae

Ophioleuce depressa

Ophiocten depressum Lyman, 1869. Bull. M. C. Z., *1*, p. 320.
Ophioleuce depressa Koehler, 1904. *Siboga* Oph., Mer. prof., p. 33.

A single very good specimen of this little known species, 6 mm. across the disk and with 2 of the long thread-like arms nearly complete, was secured at St. 3324, in the Bahia de Cochinos, southern side of Santa Clara Province, in 320 fms.

Ophiopaepale goesiana

Ljungman, 1872. Öfv. Kongl. Vet.-Akad. Förh., *28*, p. 615.

A very good adult, 8 mm. across the disk, was secured at St. 3400, in the Old Bahama Channel, off Cayo Coco, Camaguey Province, 180 fms. As the species is by no means a rarity it is a little odd that no others were secured.

Ophiopyren longispinus

Lyman, 1878. Bull. M. C. Z., *5*, p. 134.

This brittle was taken but once in 1938 but in 1939, it was found at four stations and good material was secured particularly at station 3459. The smallest specimen is 3.5 mm. across the disk, the largest is 6 mm. A very perfect specimen with disk 5 mm. across

has all the 5 arms (60-65 mm. long) practically complete. A single small specimen was taken in the Bahia de Cochinos, southern coast of Santa Clara Province, 210 fms. (St. 2962C) and another was secured at St. 3400, in the Old Bahama Channel, off Cayo Coco, Camaguey Province, 180 fms. Half a dozen specimens were collected at the eastern end of the island, Sts. 3370 and 3377, off Puerto Tanamo, Oriente Province, 450-560 fms. All the rest of the 28 specimens are from St. 3459, off Bahia Santa Clara, in Nicholas Channel, 500 fms.

Ophiernus adspersum

Lyman, 1883. Bull. M. C. Z., *10*, p. 236.

This well-nigh cosmopolitan brittle-star, characteristic of the cold depths of the sea, was met with many times by the *Atlantis* in water of 280-1800 fms. but only twice in less than 300 fms. At the eastern end of the island, it was taken (Sts. 2970, 3359, 3377) in the Windward Passage, south of Oriente, 1600-1800 fms., north of Baracoa, 1000 fms., and off Puerto Tanamo, 550 fms. On the northern coast of Santa Clara and Matanzas (Sts. 2987, 2987A, 2989, 2990A, 2990B, 2995, 3444, 3445, 3446, 3449, 3456, 3469, 3474, 3483, 3485) in 280-605 fms. it was frequent. Off Playa Baracoa, Havana Province, it occurred twice (3305, 3306) in 330 fms. The 72 specimens range from 6 to 15 mm. in disk diameter and as is almost always the case, are for the most part, in a very poor state of preservation. Adapted as it is for soft bottom in deep water, it seldom reaches the surface in uninjured condition.

ECHINOIDEA

Altho the *Atlantis* brought back 1692 echini representing 40 species, they were chiefly of those already taken by the *Blake*, at least 32 species being common to both collections. Many of the *Blake's* conspicuous novelties, such as Conolampas, Homolampas, Palaeopneustes and Linopneustes were secured in large numbers, greatly enriching the Museum collections. The striking fact that only 2 new species were secured, both in the large and widely distributed genus Clypeaster, suggests that our knowledge of the West Indian Recent echini is nearly complete, certainly much more nearly than it is in the other classes of Echinoderms. The new species of Clypeaster are very large and striking forms, quite different from any of those

previously known, and equally so from each other. The complete absence of Temnopleuridae and of Echinidae (excepting the two commonest littoral species) is a peculiar feature of the *Atlantis'* collection.

Family Cidaridae

Cidaris blakei

Dorocidaris blakei A. Agassiz, 1878. Bull. M. C. Z., *5*, p. 185.
Cidaris blakei Mortensen, 1909. Deutsch. Südpolar-Exp. Ech., p. 54.

This striking sea-urchin was taken in great numbers in 1938 at 13 stations and in 1939 at 16. The 196 specimens are nearly all adults with a horizontal diameter of 30-42 mm. The smallest has h. d. = 15 mm. and the primary spines 35-38 mm. long; several primaries are flattened at the tip, the most extreme being 5 mm. wide. The color is pale yellow fading to pure white on the collars of the primaries. The larger specimens show more or less reddish-brown, with the primaries ranging from dirty white to dark gray. The widest primary noted is 40 mm. long with the flattened tip 47 mm. wide. The primaries of all the adults are more or less overgrown with sponges, bryozoa, barnacles and worm-tubes.

The stations where *blakei* was taken in 1938 (numbers 2950, 2980, 2980A, 2980B, 2981, 2981B, 2981C, 2981D, 2982, 2982A, 2982B, 2982D and 2985) are all in the region between the southwestern Bahamas and Punta Alegre, Camaguey, in 150-285 fms. but chiefly in 150-220 fms. near Punta Alegre. In 1939, most of the stations (numbers 3385, 3386, 3388, 3392, 3405, 3410, 3411, 3412, 3432, 3436, 3440 and 3442) were also off the northern coast of Western Camaguey, in 225-335 fms., but 2 specimens of *blakei* were taken at St. 3302, off Playa Baracoa, Havana Province in 230 fms., 1 specimen was secured at St. 3374 and 1 at St. 3376, off Puerto Tanamo, Oriente in 285-300 fms. and 5 specimens were dredged at Sts. 3467 and 3478, off the Bahia de Matanzas, in 215-240 fms. It is of interest to note that *blakei* was not taken on the southern coast of Cuba.

Cidaris micans

Dorocidaris micans Mortensen, 1903. *Ingolf* Ech., pt. I, p. 23.
Cidaris micans H. L. Clark, 1925. Cat. Rec. Sea-urchins, p. 19.

A very fine specimen of this rare and beautiful sea-urchin was taken in 1939 at St. 3305, off Playa Baracoa, Havana Province, in

330 fms. It is 55 mm. h. d. and the longest spines are pure white becoming pink gradually near the base which increases abruptly in thickness. There is only the faintest tint of green on the big abactinal system.

Eucidaris tribuloides

Cidarites tribuloides Lamarck, 1816. Anim. s. Vert., *3*, p. 56.
Eucidaris tribuloides Döderlein, 1887. Jap. Seeigel, p. 42.

Inside Cabo Cruz, Oriente Province, at Sts. 3347-3350, in 11.5-13 fathoms, 30 specimens of this common littoral sea-urchin were taken, chiefly small adults (23-27 mm. h. d.) but also 10 or 12 young (8-16 mm.)

Stylocidaris affinis

Cidaris affinis Philippi, 1845. Arch. f. Naturg., *11* (1), p. 351.
Stylocidaris affinis Mortensen, 1909. Deutsch. Südpolar-Exp. Ech., p. 52.

There are 61 specimens of this common West Indian, and also Mediterranean, sea-urchin. They range in size from a young one only 8 mm. h. d. with its longest primary 20 mm., up to adults 40-47 mm. The last is considerably the largest example yet recorded. Mediterranean specimens 42 and 43 mm. h. d. have long been known but West Indian specimens over 40 mm. have not been recorded. At St. 3435, off Caibarien, Santa Clara Province, in 255 fms., the *Atlantis* took 3 specimens 40, 43 and 47 mm. h. d., with primary spines 60-80 mm. long. Specimens from St. 3465, off Bahia de Matanzas, in 175 fms. are notable for their long primaries the largest, 42 mm. h. d., has some primaries 84 mm. long, while a small one 20 mm. h. d. has primaries 60 mm. long or 3 $\times$ h. d. It is very rarely that the primaries in this species much exceed 2 $\times$ h. d.

The *Atlantis* took *affinis* at 5 stations in 1938, and at 16 in 1939. Of these 21 stations, 2 (numbers 2963C and 3330) were on the south coast in the Bahia de Cochinos, 205-265 fms. Nearly all the rest were off the Bay of Matanzas, 175-240 fms. (Sts. 3463, 3465, 3466, 3467, 3478, 3479, 3480 and 3482) or further east in the vicinity of Caibarien and Punta Alegre, 150-260 fms. (Sts. 2980A, 2980B, 2982D, 3397, 3434, 3435 and 3442). Of the remaining 4 stations, 2 (numbers 3302 and 3303) are off Playa Baracoa, Havana Province, 230-260 fathoms, one (St. 3374) was off Puerto Tanamo, Oriente, 300 fms. and one was simply "off northern coast of Cuba, 100 fms. $\pm$" – undoubtedly more!

Stereocidaris ingolfiana

Mortensen, 1903. *Ingolf* Ech., pt. 1, p. 38.

This cidarid seems to be relatively rare in the West Indies for the *Blake* secured only a few specimens, if the *Albatross* took any they have not been publicly recorded (save only Mortensen's record (1903, p. 41) of one from near Florida), and the *Atlantis* has brought back but a single specimen. It is a small one, only 21 mm. h. d. with the primary spines 35-43 mm. long. It was taken at St. 3370, northeast of Puerto Tanamo, Oriente Province, 450 fms.

Histocidaris nuttingi

Mortensen, 1926. Univ. Iowa, Studies in Nat. Hist., *11*, No. 7, p. 6.

The *Atlantis* was so fortunate as to secure 6 fine adults of this truly remarkable sea-urchin in 1938 (Sts. 2980B, 2982A and 2982B) and in 1939, tho no adults were taken, 2 young ones were dredged, one at St. 3303 and one at 3476. As the species was known hitherto only from the holotype in the University of Iowa Museum, which is 60 mm. in diameter, with the longest spine 155 mm. in length, this series from Cuba is of exceptional interest and value. The adults were all taken in the Old Bahama Channel, off Punta Alegre, Camaguey, in 205-230 fms. The largest specimen measures 75 mm. h. d. and 56 v. d. and the longest primary is 123 mm. long. The test is pale brown, the secondaires and smaller spines dirty whitish or yellowish more or less extensively tipped with light brown; the primaries are pure, more or less shining white. A slightly smaller specimen, 67 × 60 mm. is very similar in color but its primary spines are not nearly so long, none exceeding 90 mm. The 4 specimens from St. 2980B are much smaller (33-55 mm. h. d.) but have long slender spines and the test and small spines are lighter colored. The most beautiful specimen is the one from St. 3476, which is off Bahia Cardenas, Matanzas Province, in 360 fms. It is 34 mm. in diameter with the small spines pale grenish-yellow; the primary spines are very slender 100-153 mm. long. It is truly incredible that this specimen came up from such a depth with so little injury to its long, fragile spines. The smallest specimen, from off Playa Baracoa, Havana Province in 260 fms., is only 20 mm. in diameter and its primary spines are 70-85 mm. long. It is very light colored, even the smallest spines being almost white.

Histocidaris sharreri

Porocidaris sharreri A. Agassiz, 1880. Bull. M. C. Z., *8*, p. 71.
Histocidaris sharreri Mortensen, 1907. *Ingolf* Ech., pt. 2, p. 16.

There is a very small Histocidaris in the *Atlantis* collection, which is very surely not *nuttingi*. Comparison with the very large, unique holotype of *sharreri* indicates the possibility that it is the young of that species. Comparison with the half-grown *sharreri* from St. Kitts (M. C. Z. No. 253), regarding the identity of which there is room for doubt, indicates it is very probably the same species, pedicellariae and spines being quite similar. Mortensen (1928, p. 89) thinks this St. Kitts specimen represents an undescribed species but its condition is too poor to warrant making it a type. I fully concur in this conclusion and so leave it in *sharreri* and associate with it this very small cidarid taken by the *Atlantis* which is surely a Histocidaris and not *nuttingi*. The specimen is 6 mm. in diameter with 20 or more pure white, finely serrate primaries, 12-24 mm. long. It was taken at St. 3459, in Nicholas Channel, off Bahia de Santa Clara, Santa Clara Province, 500 fms.

Family Aspidodiadematidae

Aspidodiadema jacobyi

A. Agassiz, 1880. Bull. M. C. Z., *8*, p. 74.

Altho only 2 specimens of this species were taken in 1938 (Sts. 2963, 2982C) it proved to be common in 1939 and 69 were collected at 20 stations (3302, 3303, 3371, 3384, 3386, 3389, 3392, 3393, 3421, 3438, 3447, 3463, 3464, 3465, 3466, 3467, 3478, 3479, 3480 and 3482). More than half the specimens came from off the Bahia de Matanzas in 175-240 fms. while 22 were from the northern coast of Western Camaguey and eastern Santa Clara, in 195-375 fms. A single small individual was collected off Puerto Tanamo, Oriente, in 295 fms., another young one was dredged in the Bahia de Cochinos on the southern coast of Santa Clara, in 180-190 fms., and 2 others, also young, were found off Playa Baracoa, Havana Province, in 210-230 fms.

The most striking feature of this large series of a relatively rare species is the diversity of coloration. All very young specimens (i. e. under 10 mm. h. d.) are light-colored, the test and smaller spines white, the long, slender primaries pale green. This light coloration may persist, apparently even in maturity; the specimen taken at St. 2982C holds it well, and it is 18 mm. h. d. As a rule however, after 10 mm. h. d. is attained, dark purple pigment begins to appear on the apical disk and at the base of the upper primary spines and this increases more or less extensively until the whole animal, excepting the primary spines, may be very dark colored; even the primaries become a darker green, more or less tinged, at least basally, with the purple pigment. The largest specimen in the *Atlantis* collection, 22 mm. h. d. and 21 v. d., shows this dark coloration well. That it is not due to local environmental conditions is indicated by the fact that of 6 specimens from St. 3463, 3 are still without any considerable purple pigment, one has the apical disk and vicinity light purplish, a second has that area dark purple and the sixth specimen is definitely purple clear to the mouth. In most of these specimens the primary spines seem to be more nearly complete than is usually the case. They are so very slender and fragile that they are commonly badly broken in collecting. In one of these specimens from St. 3463, 12 mm. h. d., one of the spines is 40 mm. long and many others, altho undoubtedly broken, exceed 20 mm. A smaller individual, about 8 mm. in diameter has many of the primaries more than 30 mm. long and so slender they may well be called filiform. When at all nearly complete, the primaries of these specimens are distinctly curved adorally.

Plesiodiadema antillarum

Aspidodiadema antillarum A. Agassiz, 1880. Bull. M. C. Z., *8*, p. 73.
Plesiodiadema antillarum H. L. Clark, 1925. Cat. Recent Sea-Urchins, p. 39.

This species is apparently much less common than the preceding as it was not taken in 1938 and at only 3 stations (3355, 3362, 3379) near the eastern end of Cuba in very deep water (910-1070 fms.) in 1939. Obviously the apparent greater scarcity may be due to the few dredge-hauls made by the *Atlantis* at such depths. The 4 specimens at hand are small, 6-10 mm. h. d., and in poor condition. The test is light purple, the secondaries white, the primaries translucent white, or even glassy with a more or less evident purple tinge basally.

Family Centrechinidae

Centrechinus antillarum

Cidaris (Diadema) antillarum Philippi, 1845. Arch. f. Naturg. *11* (1), p. 355.
Centrechinus antillarum H. L. Clark, 1918. Bull. Univ. Iowa, Lab. Nat. Hist., *7*, no. 5, p. 24.

There are 2 specimens of this exceedingly common West Indian urchin, notorious for its poisonous primary spines. They were collected in the Ensenada de Corrientes, Pinar del Rio Province. The smaller is about 50 mm. h. d., the larger is 80 mm.

Family Echinothuriidae

Phormosoma placenta var. sigsbei

Phormosoma sigsbei A. Agassiz, 1880. Bull. M. C. Z., *8*, p. 75.
Phormosoma placenta var. *sigsbei* Mortensen, 1935. Mon. Ech., pt. II, p. 132.

This common urchin was taken at 8 stations in 1938 and at a dozen the following year. There are 69 specimens, mostly young; many are in poor condition. The best are 2 from St. 3456, 575 fms., which are a rich orange-brown in color; one is 80 mm. h. d., the largest specimen in the collection. The smallest specimen is 12 mm. h. d.; it is one of half a dozen, well preserved very light colored specimens from St. 2963D. The distribution of Phormosoma around Cuba is more than usually uniform, with a considerable bathymetrical range. In or off the big bays on the southern coast of western Cuba (Corrientes, Cochinos, Cienfuegos) 28 specimens were taken in 190-1075 fms. Further east and on the northern coast (Baracoa, Puerto Cayo Moa, Puerto Tanamo) 22 specimens were taken in 285-1075 fms. The remaining 19 were collected at 9 stations scattered along the northern coast of Camaguey and eastern Santa Clara, in 240-910 fms. Oddly enough, Phormosoma does not seem to have been taken on the rich collecting grounds off western Santa Clara and Matanzas. The stations where it was taken are 2953, 2963, 2963D, 2979, 2984, 2987, 2991, 2991A, 3328, 3338, 3359, 3365, 3366, 3367, 3371, 3374, 3376, 3385, 3456 and 3459.

Hygrosoma petersii

Phormosoma petersii A. Agassiz, 1880. Bull. M. C. Z., *8*, p. 76.
Hygrosoma petersii Mortensen, 1903. *Ingolf* Ech., pt. I, p. 58.

The *Atlantis* took this echinothurid four times in 1938 but only a single specimen was secured in 1939. The test is so flexible that

the 13 preserved specimens are very flat; they range in diameter from 27 to 110 mm. They are all more or less badly rubbed but the unrubbed areas are deep purple. The station numbers are 2969A, 2975, 2990 and 3379. All, except 2990, are east of 76° 45′ W. in 910-1800 fms. The smallest individual taken is the only specimen from 2990, which is in but 390 fms. off Puerto Sagua Grande, Santa Clara Province.

Araeosoma belli

Mortensen, 1903. *Ingolf* Ech., pt. 1, p. 55.

This is shown by the Atlantis dredgings to be by far the most abundant Cuban echinothurid. It was taken at no fewer than 46 stations, of which 36 were in 1939. These stations are 2961D, 2962, 2963, 2963A, 2963B, 2963C, 2982, 2982D, 2982E, 2999, 3319, 3320, 3334, 3341, 3374, 3377, 3386, 3390, 3391, 3393, 3396, 3397, 3398, 3399, 3400, 3403, 3404, 3405, 3406, 3409, 3411, 3412, 3413, 3414, 3415, 3416, 3417, 3418, 3419, 3420, 3427, 3465, 3478, 3480, 3482 and 3490. Of these stations, 10 are on the southern coast (9 in the Bahia de Cochinos) in 180-425 fms. Only 2 are in eastern Cuba both off Puerto Tanamo, in 300-560 fms. Near Punta Alegre and to the eastward off Camaguey are 27 statoins in 150-235 fms. Of the remaining 7 stations, 4 are off the Bahia de Matanzas, in 145-240 fms., 2 are off Caibarien, Santa Clara Province, 190-240 fms. and there is a single station off Santa Cruz del Norte, Havana Province, in 250 fms.

Altogether, 256 specimens were brought home from these numerous stations. They range in diameter from 7 to 137 mm. but the great majority are less than 100. The smallest specimens are without pigment, white or pale cream color. When the test is 10-12 mm. across, purple pigment tints the dorsal surface and as the size increases the color becomes deeper and deeper. Usually in adults the lower surface is nearly as dark as the upper but the largest of the present series is distinctly lighter below than above.

Araeosoma fenestratum

Calveria fenestrata Wyville Thomson, 1872. Proc. Roy. Soc. London, *20*, p. 494.
Araeosoma fenestratum Mortensen, 1903. *Ingolf* Ech., pt. 1, p. 52.

This is a North Atlantic species which ranges southwestward into Cuban waters. The *Atlantis* did not meet with it in 1938 but in

1939 took 2 adults and 4 very young individuals, no two at any one station. The stations are 3400, 3417, 3449, 3466, 3469 and 3479. At the first two, *Araeosoma belli* was also taken. The small specimens are 17-42 mm. in diameter, very light colored, a yellowish-white with a definite reddish tint.

The smaller adult which is about 135 mm. in diameter is of the same light, reddish coloration. The other adult, about 200 mm. in diameter, is much darker, reddish-brown, somewhat variegated with lighter and darker shades. This specimen was taken off Bahia de Matanzas in 425 fms. and two of the small ones are from the same region but in shallower water, 200-210 fms. The other adult is from further east, south of Cay Sal Bank in 390 fms. and the other two small ones still further east off the coast of Camaguey in 180-200 fms. This suggests the possibility that adults move out into deeper water as they mature.

Family Salenidae

Salenia pattersoni

A. Agassiz, 1878. Bull. M. C. Z., *5*, p. 187.

This beautiful species was rarely met with by the *Atlantis*. In 1938, a fine specimens, 12 mm. h. d., the longest spine, 65 mm., was taken at St. 2981B, in the Old Bahama Channel, off Punta Alegre, Camaguey Province, 195-225 fms. In 1939, 2 smaller specimens were collected; one 10 mm. h. d., at St. 3303, off Playa Baracoa, Havana Province, in 260 fms., and one, still smaller, only 6 mm. in diameter but very brightly colored, at St. 3482, off Bahia de Matanzas, 190 fms.

Salenocidaris profundi

Salenia profundi Duncan, 1877. Ann. Mag. Nat. Hist. (4), *20*, p. 70.
Salenocidaris profundi A. Agassiz and Clark, 1908. Mem. M. C. Z., *34*, p. 60.

A considerable series of this small deep-water urchin was taken in 1938 and a few more were added in 1939. In all there are 51 specimens from 7 stations, all in very deep water, 1020-1800 fms. Of these stations, 2 (3338 and 3344) are off the Bahia de Cienfuegos, southern coast of Santa Clara Province. All the rest (2967, 2967B, 2970, 2973 and 3362) are in the deep waters off eastern Cuba. The 51 specimens are mostly adults (12-13 mm. h. d.) and in good condition but 5 of the 7 specimens from 2967 are dead, bare tests. One

of the specimens from 2973 is notable for its long slender, straight, spines which are but little broken; the longest are 47 mm. long, about 5 × the h. d. The small specimens are light-colored with an evident lavender tint; the adults are lavender-brown. The bare tests are definitely lavender. Spines are white.

Salenocidaris varispina

A. Agassiz, 1869. Bull. M. C. Z., *1*, p. 254.

This is a much more common, or at any rate a more collectible species than the preceding as it lives in much shallower water. Very young specimens cannot be distinguished with certainty from the young of *profundi*. The *Atlantis* took 112 specimens which are here referred to this species but many of the small ones are identified chiefly by the depth at which they were taken. The largest specimen is 9 mm. h. d. with primaries 36 mm. long. The smallest specimen is only 4 mm. h. d.; oddly enough it is one of the most deeply red-purple specimens in the series and its spines are very white in sharp contrast. One of the adults has a similar striking coloration but as a rule the specimens are light, dull violet. This species was taken off the northern coast of Santa Clara Province (Sts. 2990, 2990A, 2990B, 2992, 3449, 3454 and 3459) in 390-600 fms.; off the northern coast of Oriente Province (3357, 3359, 3365, 3366, 3377 and 3379) in 560-100 fms.; and off the Bahia de Matanzas (2995, 3469) in 370-605 fms. It does not seem to have been found anywhere on the southern coast of Cuba.

Family Arbacidae

Habrocidaris scutata

Podocidaris scutata A. Agassiz, 1880. Bull. M. C. Z., *8*, p. 72.
Habrocidaris scutata A. Agassiz and Clark, 1907. Bull. M. C. Z., *50*, p. 234.

One of the choicest treasures of the *Atlantis* collection is a specimen of this very rare sea-urchin of which the holotype in the M. C. Z. has been the only one known. The *Atlantis* specimen was taken at St. 3459, in Nicholas Channel, off Bahia de Santa Clara, Santa Clara Province, in 500 fms. The unique holotype is from 580 fms. off Santa Cruz. The present specimen is smaller than the holotype and darker colored. It is 11 mm. h. d. and scarcely 4 mm. high with the oral side very flat. The 5 anal plates are evident but

neither genital nor ocular pores are visible. The spines are for the most part present, none above the long marginal series, few and small orally. The marginal spines are about 8 mm. long sharply 3-sided with each side not flat but concave or longitudinally furrowed. They are very fragile and nearly all are damaged in some way. The whole animal, spines and upper surface, lower surface and especially peristome, is silver-gray slightly tinged with brown.

Coelopleurus floridanus

A. Agassiz, 1872. Rev. Ech., pt. 1, p. 102.

It is odd that the *Atlantis* met with this species but once, for it has been not rarely taken by other vessels. There can be little doubt however that it is either a rare species or, for some reason, is hard to secure. It was not until May 11, 1939, the next to the last day of her collecting that the *Atlantis* took Coelopleurus. That day at St. 3482, off the Bahia de Matanzas, in 190 fms., she took 2 very young individuals. They are only 7 and 10 mm. h. d. and yet their colors are as bright as in the adult.

Family Echinidae

Lytechinus variegatus

Cidaris variegata Leske, 1778. Add. ad Klein, p. 85.
Lytechinus variegatus A. Agassiz, 1863. Bull. M. C. Z., *1*, p. 24.

This very common urchin is represented in the *Atlantis* collection by 21 specimens. Of these, 20 were taken in Siguanea Bay, Isle of Pines, and 1 was "bought from a fisherman" in Matanzas Bay. The last is a typical, tho small adult. Those from Siguanea Bay are young, 20-39 mm. in diameter; about half show an evident tinge of dull reddish on the primaries, as in the subspecies *L. v. carolinus.*

Tripneustes esculentus

Cidaris esculenta Leske, 1778. Add. ad Klein, p. XVII.
Tripneustes esculentus Bell, 1879. Proc. Zoöl. Soc. London, p. 657.

Three adults of this edible "sea-egg" were purchased from fishermen in Matanzas Bay. They are typical specimens 70-93 mm. in diameter. Inside Cabo Cruz, Oriente Province, (Sts. 3347-3350) a very small urchin was dredged in 11.5-13 fms., which is apparently the youngest Tripneustes (barring larval stages) that has yet been

recorded. It is only 6 mm. in diameter with primary spines 1.5-2 mm. long. The bucal membrane is thin and completely naked save for the 5 pairs of buccal plates. The color is a very pale buff, with a tinge of green on the abactinal system. The primary spines of the oral surface are faintly marked basally with rosy red. In spite of this unexpected coloration, identification as a young Tripneustes has been confirmed by comparison with the youngest Tripneustes in the M. C. Z. collection, which is 10 mm. in diameter. It has a perfectly naked buccal membrane and the spinulation and periproct are as in the smaller specimen. No trace of rosy-red however is to be found on the oral spines. Its presence in the smaller Cuban specimen is quite inexplicable.

Family Echinometridae

Echinometra lucunter

Echinus lucunter Linné, 1758. Sys. Nat. ed. 10, p. 665.
Echinometra lucunter Lovén, 1887. Bih. Svensk. Vet.Akad. Handl. *13* (4), No. 5, p. 157.

Fishermen in Matanzas Bay were the source of 8 small specimens of this extremely common urchin. They range in long diameter from 18 to 54 mm. and in color from dull brownish-gray to nearly black.

Family Clypeastridae

Clypeaster rosaceus

Echinus rosaceus Linné, 1758. Syst. Nat. ed. 10, p. 665.
Clypeaster rosaceus Lamarck, 1801. Syst. Anim. s. Vert., p. 349.

A single small specimen, 77 × 60 × 24 mm. was taken at St. 2951, northeast of Great Isaac Island, Bahamas, in 155 fms., an unusual depth for so littoral a species.

Clypeaster cyclopilus[1] sp. nov.

(Plate 10, fig. 1)

Test 215 mm. long, 220 mm. wide and 34 mm. high; as the only adult specimen is broken, the length of the type has been calculated by comparison with smaller specimens. Test rounded pentagonal, approaching circular, very flat orally. Aborally between the ends

(1) κύκλος = *circle* + πῖλος = *hat;* circular hat, in reference to the form of the test.

of the petals and the margin, which is only 7 or 8 mm. thick, it is also flat but centrally it is abruptly elevated into a "crown" about 70 mm. in diameter and 25 mm. high. Petals I and V, 70 mm. long, the poriferous areas diverging rapidly at first, then becoming nearly parallel to the fully open tip, where the petal is 37 mm. wide; measured in a straight line (i. e. not following the marked curvature of the test) these posterior petals are about 65 mm. long. Petals II and IV are almost exactly the size and form of the posterior pair. Petal III, 65 mm. long and 33 mm. wide at the fully open tip. In the unpaired petal about 52 pore-pairs may be counted on each side, in the other petals about 68; in all the petals, no pore-pairs are visible within 5-6 mm. of the madreporite. Tuberculation of test very close; near the apex, primaries are numerous and crowded, each with its definite scrobicular circle of secondaries, but passing outward towards the margin the distinction between primaries and secondaries becomes rapidly lost and over most of the dorsal surface there is a dense and fairly uniform coat of very small tubercles. On the oral surface, distinction between primaries and secondaires is again evident and the whole surface is rather evenly covered with both, about 80 primaries to a square cm., the rest of the space occupied by the secondaries. In petal III, ridges between porepairs have 3-5 (usually 4) primary tubercles and an irregular number of small ones. Madreporite small, about 4.5 mm. across, markedly convex. Periproct missing with much of the posterior end of the test. No conspicuous primary spines anywhere, but around the mouth and in the central and distal area of each interambulacral triangle orally, there are countless slender primaries 4-5 mm. long. Tridentate pedicellariae common on the oral surface and ophicephalous on the aboral but they show no characteristic features so far as noted. Color, rich yellow-brown.

Holotype, M. C. Z. No. 7667, from St .3390, in the Old Bahama Channel, off western end of Cayo Romano, Camaguey Province, 180 fms. It is unfortunate that this magnificent specimen was so badly damaged in the dredging, for most of the left posterior quadrant of the animal is missing. There are 11 paratypes but they are all young, ranging from 48 to 72 mm. in length; for the most part they are approximately circular, only 3 having the length exceeding the breadth and none being like the adult in having the breadth exceed the length. The periproct is entirely on the oral surface but very near the margin. One specimen is dark green in color, doubtless as a result of the method of preparation. The others are all light brown or yellowish brown, the oral surface usually with a greenish cast. The shape of the test and the form of the petals warrant calling these little Clypeasters the same species as the large one described

but it would be more satisfactory if there were at least one specimen of intermediate size. Altho belonging in the same section of the genus with *ravenelii*, this species is instantly distinguished by the form and tuberculation of the test and the huge, open petals.

The young individuals come from 5 different stations 3000, 3303, 3467, 3478 and 3479, but 4 of these are off the Bahia de Matanzas, in 170-255 ms. while the fifth is off Playa Baracoa, Havana Province,

Clypeaster euclastus[1] sp. nov.

(Plate 10, fig. 2)

Test 180 mm. long, 188 mm. wide, and 25 mm. high; pentagonal with concave sides and broadly rounded angles, very flat orally (the mouth but little sunken); margin thin (about 4 mm.); from edge of test there is but little increase in thickness to tips of petals (7.5-8 mm. thickness there); from there inward is a rather abrupt elevation to proximal end of petals, with very slight increase from there to the small (3.5 mm.), convex, madreporite. The test is thus of very much the same "hat-shape" as in the preceding species. Test itself very thin (.30-.50 mm.) and fragile for so large a clypeasteroid. Petals I and V rather more than 50 mm. long and 25 mm. wide at the flaring tip; the poriferous zones diverge much at first, then but slightly until at the very tip. Petals II and IV are similar but not quite so wide at the tip. Petal III is practically the same as II and IV. About 48 pore-pairs can be counted on each side of petal III, about 54 in the lateral petals. As in the previous species the pore-pairs fade out about 5 mm. from the madreporite. Tuberculation of test as in the previous species, well-marked primaries evident near madreporite, rapidly fading out over most of upper surface but becoming evident again all over the oral surface. In petal III, ridges between the pore-pairs with only 2 or 3 (rarely 4) primary tubercles and these are of small size and very irregular in position. Periproct small (4 mm. in diameter) only 2 mm. from margin. Spines extremely small and very slender; primaries 3-4 mm. long, almost filiform. Both ophicephalous and tridentate pedicellariae are present; some of the latter near the apex of the test are very large with curved valves, nearly a millimeter long, widened at the tip. Color above dull pink, more or less yellow near margin; sutures between the plates, deep pink and very evident, making the specimen unusually handsome; oral surface almost lemon yellow, the sutures not evident at all.

(1) εὔκλαστος = *fragile*, in reference to the thinness and lightness of the test.

Holotype, M. C. Z. No. 7668 from St. 3396 in the Old Bahama Channel, off Cayo Coco, Camaguey Province, 180 fms. There is a smaller paratype from the same station, 124 mm. long by 127 mm. wide, which resembles the specimen described in all essentials. It was at first supposed that these 2 Clypeasters were merely aberrant examples of the preceding species but the difference in texture and color of the test is so great, and the petals are so much less expanded at the tip, it seems sure that they represent a really distinct species.

Family Fibulariidae

Echinocyamus grandiporus

Mortensen, 1907. *Ingolf* Ech., pt. 2, p. 33.

Altho only a single living specimen of this little echinoid was taken, bare tests were collected at 3 other stations. The living specimen, about 8 mm. by 7, pale yellow in color, was found at St. 3423, with a bare test, 9 mm. by 8; this was off Caibarien, Santa Clara Province, in 245 fms. Dead tests, one at each station, were taken at 3362, off Baracoa, Oriente Province, 1020 fms.; 3450, in Nicholas Channel, south of Cay Sal Bank, 390 fms.; and 3475 off Bahia de Cardenas, Matanzas Province, 400 fms.

Echinocyamus macrostomus

Mortensen, 1907. *Ingolf* Ech., pt. 2, p. 36.

Bare tests of this deep water species were taken twice. At St. 3338, off Bahia de Cienfuegos, southern coast of Santa Clara Province, 1075 fms., 2 specimens were secured; and at St. 3379, northeast of Bahia de Nuevitas, Camaguey Province, in 910 fms. one broken specimen was taken.

Family Nucleolitidae

Conolampas sigsbei

Conoclypus sigsbei A. Agassiz, 1878. Bull. M. C. Z., *5*, p. 190.
Conolampas sigsbei A. Agassiz, 1883. *Blake* Ech., p. 48.

One of the most striking of the *Atlantis'* discoveries was the presence of this beautiful and hitherto very rare sea-urchin on both the northern and southern coasts of Cuba. A dozen specimens were brought back in 1938 but in 1939 no fewer than 80 enriched the col-

lection. The 92 specimens range in size from 40 × 38 × 27 mm. to 105 × 98 × 66 mm. The color ranges from pale yellow to deep brown but it seems evident that the darker colored specimens have been accidentally discolored by contact with other material or rust in the containers. It is probable that the color in life is always more or less as Mr. Agassiz says in his *Blake* Report, "brilliant lemon-colored". The great marine zoologist rarely expressed emotional enthusiasm in his scientific reports but of this extraordinary sea-urchin he says frankly: "This magnificent species is by far the most striking sea-urchin I have seen. I shall always remember the particular haul, when, on the edge of the Yucatan Bank, the dredge came up containing half a dozen of these huge, brilliant lemon-colored Echini." It is doubtful if that passage can be matched in all of Mr. Agassiz's writings on Echini. How he would rejoice in the superb series which the *Atlantis* has brought to his Museum! The first specimens secured in 1938 were 2 in the Bahia de Cochinos, on the southern coast, in 155-190 fms. (St. 2963A). No more were seen until near the end of the cruise when, at St. 2999, off Bahia de Matanzas, in 145-230 fms., a good series was taken. In 1939, on the first day out from Havana, off Playa Baracoa, in 260 fms. (St. 3303), 2 specimens were taken, but no more were seen for nearly 8 weeks, when off the Bahia de Matanzas, in 175-240 fms., large numbers were secured (Sts. 3463, 3465, 3467, 3478, 3479, 3480 and 3482). It would be interesting to know just what the conditions are that confine Conolampas to the vicinity of Matanzas and debar it from the rich collecting grounds further east.

Family Pourtalesiidae

Pourtalesia miranda

A. Agassiz, 1869. Bull. M. C. Z., *1*, p. 272.

Altho the *Atlantis* met with this extraordinary echinoid twice in 1938 and twice in 1939 and brought back 122 specimens all told (not counting many fragments), few of the specimens are full grown and few are whole. The test is so fragile that not many withstand the hardships of the upward journey in the dredge. The largest entire specimens in the present series are about 25 × 12 × 11 mm. Of the 122 specimens, 105 are from Nicholas Channel, off Puerto Sagua la Grande, Santa Clara, in 360-390 fms. (Sts. 2989 and 2990).

The remaining 17 were taken the next year, a few miles further east, in 390-405 fms. (Sts. 3450 and 3451). Evidently Pourtalesia is "local" if not rare.

Family Aeropsidae

Aceste bellidifera

Wyville Thomson, 1877. Voy. *Challenger*: The Atlantic, *1*, p. 376.

A fine adult specimen in perfect condition was taken, of this very rare spatangoid, in 1938, at St. 2990B, in Nicholas Channel, off Puerto Sagua la Grande, Santa Clara, 415 fms. It is $30 \times 22 \times 14$ mm. and light gray-brown in color with the curious paddle-shaped primaries, silvery white. In 1938, a smaller specimen, $20 \times 15 \times 10$ mm. and completely yellowish-white in color was taken on the other side of Cuba, at St. 3345, off Banco Paz, south of Santa Clara Province, in 690-700 fms. Is the lighter coloration a consequence of the much greater depth?

Family Palaeopneustidae

Archaeopneustes hystrix

Palaeopneustes hystrix A. Agassiz, 1880. Bull. M. C. Z., *8*, p. 82.
Archaeopneustes hystrix Gregory, 1892. Quart. Jour. Geol. Soc. London, *48*, page 163.

This was one of the *Blake's* most notable discoveries and has seldom been reported since but the *Atlantis* found it common both in 1938 and 1939. In all, 48 specimens were brought back. These range in size from a pale brown young one, $12 \times 10 \times 7$ mm. to a splendid rich red-purple adult, $138 \times 104 \times 68$ mm. When about 40 mm. long the red-purple coloring becomes evident on the test, increasing in amount and in depth of shade with increased size, but the primary spines show little purple until the animal is about 100 mm. long. In 1938, the first specimens were taken in the Bahia de Cochinos, southern Santa Clara, 190-270 fms. (Sts. 2960, 2963, 2963C), and more were taken near the western end of the Old Bahama Channel, off northern Camaguey, in 150-260 fms. (Sts. 2982A, 2982D, 2983). The following year Archaeopneustes was taken off Puerto Tanamo, Oriente Province, 285 fms. (St. 3376) and also off the Bahia de Matanzas, 190-425 fms. (Sts. 3469 and 3482) but all

the rest of the material is from the Old Bahama Channel, between 78° 8′ and 78° 19′ W., in 180-220 fms. (Sts. 3386, 3389, 3390, 3397, 3398 and 3400).

Palaeopneustes cristatus

A. Agassiz, 1873. Bull. M. C. Z., *3*, p. 188.

This was one of the *Hassler's* striking discoveries and was subsequently taken by the *Blake* but it has remained for the *Atlantis* to demonstrate how common it is in favored areas around Cuba. It was taken in the Bahia de Cochinos, southern Santa Clara, in 205 fms. (St. 2963C); off the Bahia de Matanzas, 170-255 fms. (St. 3000) and at half a dozen places in the Old Bahama Channel, off western Camaguey, between 78° 11′ and 79° W., in 180-220 fms. (Sts. 3386, 3393, 3398, 3408, 3418 and 3419). At 4 stations it occurred with Archaeopneustes.

There were 78 specimens brought home, mostly adult, but they range in size from a bare test 78 × 67 × 51 mm. to a bristling beauty 125 × 110 × 75 mm. The color ranges from purplish-brown to very deep purple, in a few cases almost black. No very young individuals were taken.

Palaeotropus josephinae

Lovén, 1872. Öfv. Vet.-Akad. Förh. f. 1871, No. 8, p. 21.

A small specimen of this spatangoid was taken at St. 2982A, off Punta Alegre, Camaguey Province, in 210 fms. but it is rather badly crushed. A somewhat smaller specimen, about 15 mm. long, from St. 3482, off the Bahia de Matanzas, in 190 fms. is also damaged. But a small adult, 24 × 20 × 11 mm., taken at St. 3303, off Playa Baracoa, Havana Province, in 260 fms. is in perfect condition. The subanal fasciole is well developed and there are only 2 genital pores.

Homolampas fragilis

Lissonotus fragilis A. Agassiz, 1869. Bull. M. C. Z., *1*, p. 273.
Homolampas fragilis A. Agassiz, 1872. Rev. Ech., pt. 1, p. 137.

This is apparently a very rare species, as there are but 3 specimens in the M. C. Z., the 2 very small ones on which the species is based and fragments of a very large one taken by the *Blake* in 1920 fms. in the Gulf of Mexico. The *Atlantis* has brought back 22 specimens,

all of small size but in excellent condition. They were taken, in 1938, in Nicholas Channel, off northern Santa Clara, between 80° 4′ and 80° 12′ W., in 360-415 fms. (Sts. 2989, 2990, 2990A, 2990B); there are 14 specimens, 19-29 mm. in length. A single small specimen was taken further west off Bahia de Cardenas, Matanzas Province, in 365 fms. (St. 2998A). In 1939, in the same area, in 380-500 fms., (Sts. 3449, 3450 and 3459), 6 more specimens were secured ranging from 24 to 31 mm. in length. All of these 21 specimens appear to be mature as the 3 genital pores are relatively large and in the 24 mm. specimen, a fourth is present, tho smaller. At St. 3386, in the Old Bahama Channel, off the western end of Cayo Romano, Camaguey Province, in 220 fms., a single Homolampas was taken which is notable for two reasons. The color is silvery-gray with a violet tinge, while all the other specimens are pale-brown, cream-color or nearly white. The size is $35 \times 28 \times 14$ mm. and there are 4 genital pores. The question naturally arises whether this specimen can be considered even approximately full-grown. If so, it is doubtful whether the large specimen taken by the *Blake* in the Gulf of Mexico can be referred to *fragilis* for re-examination of those fragments shows that the specimen was fully 80 mm. long in life and had 9 or 10 big primary tubercles in interambulacrum 5. None of the *Atlantis* specimens have a primary tubercle in that area, but in all the other 4 they are present and in the largest specimen, they are numerous. Until specimens intermediate in size are secured judgment on this matter must be suspended.

Family Hemiasteridae

Hemiaster expergitus

Lovén, 1872. Öfv. Vet.-Akad. Förh. f. 1871, No. 8, p. 6.

This is another North Atlantic species which extends its range into the West Indian region. But it does not appear to be very common there as the *Atlantis* secured only 2 specimens, one each year. In 1938, a pale yellowish individual, $13 \times 11 \times 9$ mm., was taken at St. 2982, in the Old Bahama Channel, off Punta Alegre, in 210 fms. In 1939, a somewhat larger individual, $16 \times 16 \times 12$ mm., was taken just a little further west, at St. 3428, off Caibarien, Santa Clara Province, in 240 fms. In this specimen the test is white but the muscles attaching the white spines are brown and give a pale brown-

ish aspect to the animal as a whole. The conspicuous fasciole is greenish-brown.

Schizaster orbignyanus

A. Agassiz, 1880. Bull. M. C. Z., *8*, p. 84.

This has hitherto been a rarity and there has been some question as to its status but the material brought home by the *Atlantis* is adequate to settle all doubts. The 21 specimens range in size from a young one 22 × 20 × 14 mm. to a bare test, 65 × 60 × 39 mm. The latter is one of 5 such tests dredged at St. 3328, in the Bahia de Cochinos, southern coast of Santa Clara Province, 260-275 fms. Of these 2 are semi-fossil and more or less covered with extraneous growths (worm-tubes, etc.). The largest is however in fine condition and shows the fascioles well. The largest specimens with spines on measure 48 × 40 × 28 and 48 × 43 × 29 mm.; they differ also in color, the narrower being very pale brown, the peripetalous fasciole somewhat darker, while the wide one is a rather bright and light red-brown with the fascioles a very dark blackish brown in handsome contrast. Smaller specimens are usually light-colored, specimens under 25 mm. long being almost white, but the fascioles are deep purple or very dark brown in striking contrast. This conspicuous appearance of the fascioles appears to be a good species character.

This valuable and interesting lot of Schizasters were taken in only 2 areas, the Bahia de Cochinos, southern Santa Clara, 260-275 fathoms. (Sts. 2960 and 3328) and in the Old Bahama Channel, off northern Camaguey, between 78° 9′ and 78° 45′ W., 195-260 fms. (Sts. 2982C, 3386, 3388, 3405, 3410 and 3411).

Family Spatangidae

Brissopsis atlantica

Mortensen, 1907. *Ingolf* Ech., pt. 2, p. 160.

This proves to be one of the commonest of West Indian spatangoids and the *Atlantis* found it frequently both years. There are in all 158 specimens from 31 stations. They range in size from very fragile young ones (9 × 7 × 6.5 mm.) to a full grown adult (70 × 52 × 35 mm.), but the great majority are young or half grown. The very young ones are very light colored, often nearly white, with the fascioles darker, but after a length of about 40mm.

is attained, the color is darker and adults are dark olive-green or dark brown and the fascioles no longer stand out clearly. The stations where this material was collected are chiefly in the Old Bahama Channel on the northern coast of Camaguey Province and eastern Santa Clara, between 78° 8′ and 79° 22′ W., 150-260 fms. (Sts. 2981C, 2981D, 2982, 2982A, 2982D, 2982E, 2983, 3386, 3387, 3388, 3391, 3392, 3401, 3403, 3405, 3410, 3411, 3412, 3413, 3414, 3415 and 3428). A few were taken further west off the Bahia de Matanzas, 240-425 fathoms. (Sts. 3460 and 3469), and further east off Puerto Tanamo, Oriente Province, 230-300 fms. (Sts. 3374, 3375, 3376). Brissopsis was also taken several times off the southern coast of Santa Clara Province; in the Bahia de Cochinos, 190-275 fms. (Sts. 3328 and 3333), off Cienfuegos, 1440 fms. (St. 3344) and off Banco Paz, 690-700 fms. (St. 3345).

Meoma ventricosa

Spatangus ventricosus Lamarck, 1816. Anim. s. Vert., *3*, p. 29.
Meoma ventricosa Lütken, 1864. Vid. Med. f. 1863, p. 120.

There are 4 specimens from Matanzas Bay of this common shallow-water spatangoid. One is labelled as taken at St. 2999, but as the depth there was 145-230 fms., it is probable that there is some mistake and all four specimens were "bought from fishermen" as two other labels say. The specimens are large adults, the largest 134 × 112 × 61 mm.

Plethotaenia spatangoides

Macropneustes spatangoides A. Agassiz, 1883. *Blake* Ech., p. 64.
Plethotaenia spatangoides H. L. Clark, 1917. Mem. M. C. Z., *46*, p. 222.

This is another spatangoid, supposedly very rare of which few were known; the M. C. Z. had only bare and broken fragments from the *Blake* collection. The *Atlantis* however has secured a most interesting series of 31 specimens from 14 stations. All are adults but they show remarkable diversity in size and form. The smallest is 80 × 73 × 42 mm. but this individual is unusually high. A very flat specimen is 85×83×39 mm. while a very high one is 87×81×48 mm. The largest is 115 × 118 × 50 mm., the flattest of all. There is also much diversity of color; dark brown with hardly a trace of violet, light brown with more or less of a violet tint to the test, dark brown with a violet cast, and bright violet tending now and then to purple.

This fine lot was taken at 14 different stations, beginning with an

uninjured adult from the western part of the northwestern Providence Channel, Bahamas, 285 fms. (St. 2950), February 3, 1938. Most of the material was taken between 78° 48′ and 79° 35′ W., off the eastern end of Santa Clara Province and the western corner of Camaguey, in 195-260 fms. (Sts. 2980B, 2981, 2981B, 2982A, 2983, 2984, 3432, 3434, 3435, 3436) but 3 specimens were secured off Puerto Tanamo, Oriente, in 300 fms. (St. 3374) and 2 came from off the Bahia de Matanzas, 315-285 fms. (Sts. 3467 and 3483). No specimens were taken on the southern coasts of the island.

Linopneustes longispinus

Eupatagus longispinus A. Agassiz, 1878. Bull. M. C. Z., *5*, p. 191.
Linopneustes longispinus A. Agassiz, 1880. Bull. M. C. Z., *8*, p. 82.

This was a *Blake* discovery and has been considered something of a rarity but the *Atlantis* has proved it to be so abundant in some areas off the Cuban coast as to be nothing less than a nuisance, with its heavy coat of porcupine-like spines. The 166 specimens brought home range in size from young ones less than 30 mm. long ($28 \times 23 \times 7$ is the smallest) to the full grown adults, exceeding 100 mm. ($142 \times 125 \times 50$ is the largest). In color they show equal diversity; the young are white, pale cream color or pale flesh-color; as they grow, they become yellow, reddish or gray-brown and many large ones are dark brown. But the long primary spines (30-50 mm.) are always more or less nearly white. The marginal fasciole varies in its conspicuousness but in some of the light colored specimens it stands out as a striking dark-colored narrow band just at the edge of the test.

This fine series of specimens was collected at more than 40 stations. Scattered localities were in the Bahamas (St. 2950); at Playa Baracoa, Havana Province, Cuba, 230 fms. (St. 3302) and off Puerto Tanamo, Oriente, 295 fms. (St. 3371). A number of specimens were secured in the Bahia de Cochinos, southern Santa Clara, in 150-320 fathoms. (Sts. 2960, 2961D, 2962D, 2963B, 2963D, 2963E, 3320 and 3323) and some off the Bahia de Matanzas, northern coast of Matanzas in 145-240 fms. (Sts. 2999, 3460, 3478, 3480 and 3482). But it was along the northern coasts of western Camaguey and eastern Santa Clara, between 78° and 80° W., in 190-390 fms. that the great bulk of the material was taken (Sts. 2980, 2980A, 2980B, 2981, 2981B, 2981C, 2981D, 2982, 2982A, 2983, 2984, 2987, 2987C, 2990, 3384, 3386, 3404, 3413, 3414, 3415, 3417, 3431, 3434, 3437 and 3443).

LIST OF STATIONS

AT WHICH ECHINODERMS WERE TAKEN AND THE SPECIES SECURED AT EACH

In listing the stations where echinoderms were found, it seems desirable to group them in such a way that the eastern and western ends of Cuba, and the northern and southern coasts may be compared, even tho the far larger number of stations on the northern coast obviously distorts the picture. The stations are easily grouped as follows: Western, those west of long. 84° W.; Southern, along the south coast between 84° and 78° W.; Eastern, those east of 78° W.; Northern, along the north coast between 78° and 84° W., including a very few stations in the southwestern Bahamas. The species are arranged systematically.

WESTERN STATIONS:

These call for but little comment, as only 16 species are involved, 14 of which were taken elsewhere. An arm of *Brisinga verticillata* and the unique holotype of *Ophiomusium moniliforme* are the only novelties from this area.

2953 – 615 fms. 5 species.
Persephonaster spinulosus, Plinthaster dentatus, Ophiomusium moniliforme, Ophioceramis rugosa, Phormosoma placenta var. sigsbei.

3313 – 550 fms. 7 species.
Persephonaster spinulosus, Cheiraster coronatus, Ceramaster grenadensis, Nymphaster arenatus, Ophiomusium lymani, Ophiozonella nivea, Ophiozonella granulifera.

3314 – 500 fms. 1 species.
Goniopecten demonstrans.

3315 – 350 fms. 6 species.
Cheiraster mirabilis, Brisinga verticillata, Ophiocamax fasciculata, Ophiomusium eburneum, Ophiomusium lymani, Ophiozonella nivea.

SOUTHERN STATIONS:

Of the 33 stations in this group, 29 are in the Bahia de Cochinos. Of the 70 species of echinoderms taken, 63 were found there. The resemblance between the fauna of that bay and that of the northern coast of Santa Clara Province is striking. Many species occur

in the two regions which were not taken either east or west of Santa Clara, and while this may be due merely to the chances of dredging, it suggests the idea that in earlier days there was direct marine communication between the Bahia de Cochinos and the northern coast of Cuba. Of the 63 species found in the bay, 3 crinoids, 6 seastars and 2 brittle-stars were not taken anywhere else, and 4 of these 11 species were hitherto unknown.

2960 – 270 fms. 8 species.
Caryometra atlantidis, Prionaster elegans, Cheiraster coronatus, Amphiura otteri, Ophiomusium validum, Archaeopneustes hystrix, Schizaster orbignyanus, Linopneustes longispinus.

2961 – 250-255 fms. 1 species.
Ophioprium cervicorne.

2961D – 195-235 fms. 4 species.
Prionaster elegans, Henricia microspina, Araeosoma belli, Linopneustes longispinus.

2962 – 200-210 fms. 3 species.
Asteroschema oligactes, Ophiozonella tessellata, Araeosoma belli.

2962A – 215-225 fms. 2 species.
Neocomatella pulchella, Odinia pandina.

2962B – 180-190 fms. 1 species.
Peltaster hebes.

2962C – 210 fms. 2 species.
Anthenoides peircei, Ophiopyren longispinus.

2962D – 175-210 fms. 1 species.
Linopneustes longispinus.

2963 – 190-180 fms. 6 species.
Democrinus rawsonii, Ophiozonella tessellata, Aspidodiadema jacobyi, Phormosoma placenta var. sigsbei, Araeosoma belli, Archaeopneustes hystrix.

2963A – 155-190 fms. 5 species.
Luidiaster mixtus, Pedicellaster pourtalesi, Ophiomusium validum, Araeosoma belli, Conolampas sigsbei.

2963B – 150-170 fms. 6 species.
Prionaster elegans, Henricia microspina, Ophiocamax fasciculata, Ophiomusium validum, Araeosoma belli, Linopneustes longispinus.

2963C – 205 fms. 8 species.
Asteroschema laeve, Asteroschema oligactes, Ophiomusium validum, Ophiozonella tessellata, Stylocidaris affinis, Araeosoma belli, Archaeopneustes hystrix, Palaeopneustes cristatus.

2963D – 220-275 fms. 4 species.
Caryometra atlantidis, Ophiozonella nivea, Phormosoma placenta var. sigsbei, Linopneustes longispinus.

2963E – 220-235 fms. 4 species.
Nymphaster subspinosus, Pedicellaster pourtalesi, Asteronyx loveni, Linopneustes longispinus.

2963f – 375-400 fms. 1 species.
Luidiaster enoplus.

3319 – 195-215 fms. 5 species.
Anthenoides peircei, Henricia antillarum, Ophiomusium stellatum, Ophiomusium validum, Araeosoma belli.

3320 – 185 fms. 10 species.
Caryometra alope, Caryometra spinosa, Pseudarchaster parelii, Ophiotreta mixta, Placophiothrix suensonii, Ophiura acervata, Ophiomusium acuferum. Ophiomusium validum, Araeosoma belli, Linopneustes longispinus.

3323 – 290-320 fms. 13 species.
Neocrinus blakei, Neocrinus decorus, Endoxocrinus prionodes, Prionaster elegans, Nymphaster arenatus, Nymphaster subspinosus, Anthenoides peircei, Remaster palmatus, Ophiomyxa tumida, Ophiogeron granulatus, Ophiomusium lymani, Ophiosphalma dyscritum, Linopneutes longispinus.

3324 – 320 fms. 7 species.
Neocrinus blakei, Ophidiaster pinguis, Ophiomyxa tumida, Ophiogeron granulatus, Ophiomusium lymani, Ophiozonella nivea, Ophileuce depressa.

3325 – 300 fms. 2 species.
Henricia antillarum, Odinia pandina.

3326 – 265 fms. 11 species.
Endoxocrinus parrae, Endoxocrinus prionodes, Neocomatella pulchella, Crinometra insculpta, Crinometra pulchra, Caryometra spinosa, Luidiaster dubius, Mediaster pedicellaris, Tremaster laevis, Asteroschema oligactes, Ophiomitra valida.

3328 – 260-275 fms. 6 species.
Prionaster elegans, Ophiomyxa tumida, Ophioprium cervicorne, Phormosoma placenta var. sigsbei Schizaster orbignyanus, Brissopsis atlantica.

3330 – 230-265 fms. 1 species.
Stylocidaris affinis.

3331 – 230-260 fms. 4 species.
Prionaster elegans, Ophiomusium validum, Ophiozonella nivea, Ophiozonella tessellata.

3332 – 175-225 fms. 3 species.
Amphiura otteri, Amphitarsus mirabilis, Ophiomusium validum.

3333 – 190-200 fms. 8 species.
Pseudarchaster parelii, Pedicellaster pourtalesi, Amphiura otteri, Ophiomusium eburneum, Ophiomusium validum, Ophiomusium microporum, Ophiozonella nivea, Brissopsis atlantica.

3334 – 185-195 fms. 3 species.
Ophiura acervata, Ophiomusium validum, Araeosoma belli.

3335 – 200 fms. 4 species.
Pseudarchaster parelii, Henricia microspina, Ophiomusium acuferum, Ophiomusium validum.

3336 – 200-240 fms. 3 species.
Pseudarchaster parelii, Ophiomusium validum, Ophiozonella tessellata.

3338 – 1075 fms. 6 species.
Nymphaster arenatus, Ophiura lepida, Ophiomusium lymani, Phormosoma placenta var. sigsbei, Salenocidaris profundi, Echinocyamus macrostomus.

3341 – 310-425 fms. 3 species.
Atelecrinus pourtalesii, Ophiozonella nivea, Araeosoma belli.
3344 – 1440 fms. 3 species.
Ophiomidas dubius, Salenocidaris profundi, Brissopsis atlantica.
3345 – 690-700 fms. 3 species.
Ophiura lepida, Aceste bellidifera, Brissopsis atlantica.

Eastern Stations:

In this group, 29 station numbers are included but on the labels with the specimens, stations 3347, 3348, 3349 and 3350, inside Cabo Cruz in shallow water, 11.5-13 fms., are treated as a single station and are accordingly listed as such here. Of the 26 stations, only 6 are south of Cape Maysi and of the remaining 20, 8 are off Puerto Tanamo, Oriente Province. The stations south of Cape Maysi, excepting only those already mentioned inside of Cabo Cruz, are in very deep water, 1010-1800 fms. and several sea-stars and brittle-stars not taken elsewhere occurred here but on the whole there is little that is distinctive in this Eastern group of stations.

2967 – 1530 fms. 2 species.
Ophiosphalma armigerum, Salenocidaris profundi.
2967B – 1330-1650 fms. 2 species.
Ophiosphalma serratum, Salenocidaris profundi.
2969A – 1010 fms. 2 species.
Freyella trispinosa, Hygrosoma petersii.
2970 – 1600-1800 fms. 12 species.
Persephonaster leptactis, Nymphaster arenatus, Litonotaster intermedius, Hymenaster pellucidus, Freyella elegans, Bathypectinura lacertosa, Homalophiura abyssorum, Ophiosphalma armigerum, Ophiosphalma serratum, Ophiernus adspersum, Hygrosoma petersii, Salenocidaris profundi.
2973 – 1245-1335 fms. 3 species.
Bathypectinura lacertosa, Ophiosphalma armigerum, Salenocidaris profundi.
2975 – 1015 fms. 7 species.
Monachocrinus caribbaeus, Plutonaster bifrons, Benthopecten spinosus, Hymenaster regalis, Bathypectinura lacertosa, Ophiosphalma serratum, Hygrosoma petersii.
2976 – 1450 fms. 1 species.
Ophiosphalma armigerum.
2979 – 790 fms. 2 species.
Ophiura lepida, Phormosoma placenta var. sigsbei.
3347 – 3350, 11.5-13 fms. 8 species.
Oreaster reticulatus, Echinaster sentus, Ophiomyxa brevicauda, Placophiothrix suensonii, Ophioderma brevispinum, Ophiolepis elegans, Eucidaris tribuloides, Tripneustes esculentus.

3355 – 1070 fms. 7 species.
Benthopecten spinosus, Cheiraster coronatus, Litonotaster intermedius, Ophiacantha echinulata, Homalophiura abyssorum, Ophiosphalma serratum, Plesiodiadema antillarum.

3357 – 875 fms. 3 species.
Pseudarchaster concinnus, Ophioplinthaca dipsacos, Salenocidaris varispina.

3359 – 1000 fms. 10 species.
Plutonaster bifrons, Luidiaster mixtus, Ceramaster grenadensis, Amphiophiura metabula, Ophiura lepida, Ophiomusium lymani, Ophiosphalma serratum, Ophiernus adspersum, Phormosoma placenta var. sigsbei, Salenocidaris varispina.

3362 – 1020 fms. 6 species.
Benthopecten spinosus, Ophiosphalma serratum, Ophiomidas dubius, Plesiodiadema antillarum, Salenocidaris profundi, Echinocyamus grandiporus.

3363 – 830 fms. 5 species.
Plutonaster bifrons, Cheiraster coronatus, Ceramaster grenadensis, Nymphaster arenatus, Ophiomusium leptobrachium.

3365 – 600 fms. 4 species.
Amphiura otteri, Ophiozonella granulifera, Phormosoma sigsbei, Salenocidaris varispina.

3366 – 625 fms. 5 species.
Goniopecten demonstrans, Ophiogeron granulatus, Ophiosphalma serratum, Phormosoma placenta var. sigsbei, Salenocidaris varispina.

3367 – 640 fms. 2 species.
Persephonaster spinulosus, Phormosoma placenta var. sigsbei.

3370 – 450 fms. 8 species.
Persephonaster spinulosus, Cheiraster coronatus, Amphiophiura metabula, Bathypectinura lacertosa, Ophiomusium lymani, Ophiosphalma serratum, Ophiopyren longispinus, Stereocidaris ingolfiana.

3371 – 295 fms. 11 species.
Mammaster sigsbei, Ophiocreas spinulosum, Asteronyx loveni, Ophioprium cervicorne, Bathypectinura lacertosa, Amphiophiura oedignatha, Ophiomusium lymani, Ophiosphalma dyscritum, Aspidodiadema jacobyi, Phormosoma placenta var. sigsbei, Linopneustes longispinus.

3372 – 300 fms. 1 species.
Crinometra insculpta.

3374 – 300 fms. 11 species.
Ophiomyxa tumida, Ophiacantha scutata, Amphiophiura oedignatha, Ophiomusium lymani, Ophiozonella nivea, Cidaris blakei, Stylocidaris affinis, Phormosoma placenta var. sigsbei, Araeosoma belli, Brissopsis atlantica, Plethotaenia spatangoides.

3375 – 230 fms. 7 species.
Prionaster elegans, Pedicellaster pourtalesi, Ophiomyxa tumida, Ophioplax spinulifera, Amphiophiura oedignatha, Ophiomusium validum, Brissopsis atlantica.

3376 – 285 fms. 8 species.
Ophiomyxa tumida, Ophiacantha scutata, Ophiomusium validum, Ophiozo-

nella nivea, Cidaris blakei, Phormosoma placenta var. sigsbei, Archaeopneustes hystrix, Brissopsis atlantica.

3377 – 560 fms. 7 species.
Ceramaster grenadensis, Nymphaster arenatus, Ophiacantha echinulata, Ophiopyren longispinus, Ophiernus adspersum, Araeosoma belli, Salenocidaris varispina.

3379 – 910 fms. 6 species.
Ophiacantha echinulata, Ophiomusium lymani, Plesiodiadema antillarum, Hygrosoma petersii, Salenocidaris varispina, Echinocyamus macrostomus.

3380 – 460 fms. 1 specie.
Ophiacantha echinulata.

Northern Stations:

The great bulk of the *Atlantis* collections came from the northern coast of Camaguey, Santa Clara, Matanzas and Havana Provinces in depths of 145-665 fms., but for the most part in 200-350 fms. There were 50 stations in the Old Bahaman Channel, 27 in Nicholas Channel and 16 off the Bahia de Matanzas, where echinoderms occurred. At many of these 10 or more species were taken and at 7, 20 or more were secured. The largest number at any one station was 30 at St. 3482, off Bahia de Matanzas, in 190 fms. but 28 were taken at St. 3478 in the same region, in 240 fms. and 27 at St. 3303, off Playa Baracoa, Havana Province, in 260 fms. Obviously conditions along this coast are very favorable for echinoderms.

2950 – 285 fms. 11 species.
Crinometra insculpta, Henricia microspina, Ophiogeron granulatus, Ophiacantha scutata, Amphiophiura oedignatha, Ophiomusium lymani, Ophiomusium microporum, Ophiosphalma dyscritum, Cidaris blakei, Plethotaenia spatangoides, Linopneustes longispinus.

2951 – 155 fms. 1 species.
Clypeaster rosaceus.

2980 – 250 fms. 6 species.
Crinometra insculpta, Marginaster pectinatus, Pteraster rugosus, Ophiura acervata, Cidaris blakei, Linopneustes longispinus.

2980A – 220-260 fms. 10 species.
Crinometra insculpta, Astropecten articulatus, Zoroaster ackleyi, Ophiomyxa tumida, Astrospartus mucronatus, Ophiacantha scutata, Ophiura acervata, Cidaris blakei, Stylocidaris affinis, Linopneustes longispinus.

2980B – 220-225 fms. 20 species.
Neocrinus blakei, Crinometra insculpta, Astropecten articulatus, Nymphaster subspinosus, Ophidiaster alexandri, Henricia microspina, Zoroaster ackleyi, Asteroschema intectum, Asteroschema oligactes, Asteronyx loveni, Astrogomphus vallatus, Astrospartus mucronatus, Ophiomitra valida, Ophiotreta lineolata, Ophiura acervata, Cidaris blakei, Stylocidaris affinis, Histocidaris nuttingi, Plethotaenia spatangoides, Linopneustes longispinus.

2981 – 225 fms. 6 species.
Cheiraster coronatus, Tessellaster notabilis, Ophiura acervata, Cidaris blakei, Plethotaenia spatangoides, Linopneustes longispinus.

2981B – 195-225 fms. 9 species.
Luidiaster mixtus, Mediaster pedicellaris, Nymphaster subspinosus, Mammaster sigsbei, Ophiomusium validum, Cidaris blakei, Salenia pattersoni, Plethotaenia spatangoides, Linopneustes longispinus.

2981C – 195 fms. 6 species.
Luidiaster mixtus, Asteroschema laeve, Ophiomusium validum, Cidaris blakei, Brissopsis atlantica, Linopneustes longispinus.

2981D – 190-230 fms. 5 species.
Ophiacantha scutata, Ophiomusium validum, Cidaris blakei, Brissopsis atlantica, Linopneustes longispinus.

2982 – 210 fms. 9 species.
Caryometra alope, Prionaster elegans, Cheiraster coronatus, Ophiomusium microporum, Cidaris blakei, Araeosoma belli, Hemiaster expergitus, Brissopsis atlantica, Linopneustes longispinus.

2982A – 210 fms. 13 species.
Crinometra insculpta, Prionaster elegans, Cheiraster coronatus, Henricia microspina, Ophiotreta sertata, Ophiomusium validum, Cidaris blakei, Histocidaris nuttingi, Archaeopneustes hystrix, Palaeotropus josephinae, Brissopsis atlantica, Plethotaenia spatangoides, Linopneustes longispinus.

2982B – 205-230 fms. 15 species.
Crinometra insculpta, Astropecten articulatus, Zoroaster ackleyi, Mammaster sigsbeei, Astrogomphus vallatus, Astrospartus mucronatus, Ophiacantha scutata, Ophiotreta lineolata, Ophiotreta sertata, Ophiura acervata, Ophiomusium validum, Cidaris blakei, Histocidaris nuttingi.

2982C – 195-225 fms. 12 species.
Crinometra insculpta, Caryometra alope, Astropecten articulatus, Luidiaster mixtus, Anthenoides peircei, Zoroaster ackleyi, Mammaster sigsbeei, Ophiocamax fasciculata, Ophiura acervata, Ophiomusium validum, Aspidodiadema jacobyi, Schizaster orbignyanus.

2982D – 150-180 fms. 9 species.
Astropecten articulatus, Cheiraster coronatus, Nymphaster subspinosus, Ophiacantha scutata, Cidaris blakei, Stylocidaris affinis, Araeosoma belli, Archaeopneustes hystrix, Brissopsis atlantica.

2982E – 150-180 fms. 5 species.
Cheiraster coronatus, Ophiomyxa tumida, Ophioplax spinulifera, Araeosoma belli, Brissopsis atlantica.

2983 – 235-260 fms. 8 species.
Crinometra insculpta, Nymphaster subspinosus, Mammaster sigsbeei, Ophiacantha scutata, Archaeopneustes hystrix, Brissopsis atlantica, Plethotaenia spatangoides, Linopneustes longispinus.

2983A – 235 fms. 6 species.
Crinometra insculpta, Caryometra atlantidis, Nymphaster subspinosus, Zoroaster ackleyi, Mammaster sigsbeei, Ophiocamax fasciculata.

2984 – 240-250 fms. 11 species.
Crinometra insculpta, Prionaster elegans, Luidiaster mixtus, Nymphaster

subspinosus, Plinthaster dentatus, Ophidiaster alexandri, Mammaster sigsbeei, Ophiotreta sertata, Phormosoma placenta var. sigsbeei, Plethotaenia spatangoides, Linopneustes longispinus.

2985 – 250 fms. 7 species.
Nymphaster subspinosus, Plinthaster dentatus, Henricia microspina, Mammaster sigsbeei, Ophiacantha scutata, Ophiocamax fasciculata, Cidaris blakei.

2987 – 280-300 fms. 14 species.
Crinometra insculpta, Cheiraster mirabilis, Nymphaster subspinosus, Plinthaster dentatus, Zoroaster ackleyi, Mammaster sigsbeei, Astrodia tenuispina, Ophiacantha scutata, Ophiocamax fasciculata, Ophiomusium lymani, Ophiosphalma dyscritum, Ophiernus adspersum, Phormosoma sigsbeei, Linopneustes longispinus.

2987A – 285-300 fms. 15 species.
Persephonaster echinulatus, Cheiraster mirabilis, Nymphaster subspinosus, Plinthaster dentatus, Ophioscolex tropicus, Astrodia tenuispina, Ophiacantha scutata, Ophiocamax fasciculata, Ophiochiton grandis, Ophiura falcifera, Ophiura lepida, Ophiomusium eburneum, Ophiomusium lymani, Ophiosphalma dyscritum, Ophiernus adspersum.

2987C – 300-315 fms. 12 species.
Persephonaster echinulatus, Cheiraster mirabilis, Nymphaster subspinosus, Plinthaster dentatus, Henricia microspina, Pteraster caribbaeus, Ophiacantha echinulata, Ophiocamax fasciculata, Ophiomusium lymani, Ophiosphalma dyscritum, Ophioceramis rugosa, Linopneustes longispinus.

2987D – 315 fms. 6 species.
Persephonaster echinulatus, Cheiraster mirabilis, Ceramaster grenadensis, Nymphaster arenatus, Plinthaster dentatus, Ophiocamax fasciculata.

2987E – 315 fms. 2 species.
Nymphaster arenatus, Ophiocamax fasciculata.

2988 – 380 fms. 4 species.
Persephonaster echinulatus, Ceramaster grenadensis, Nymphaster arenatus, Henricia microspina.

2989 – 360 fms. 8 species.
Bythocrinus conifer, Caryometra alope, Persephonaster echinulatus, Nymphaster arenatus, Ophiacantha echinulata, Ophiernus adspersum, Pourtalesia miranda, Homolampas fragilis.

2990 – 390 fms. 8 species.
Caryometra lisa, Atelecrinus balanoides, Amphiura otteri, Hygrosoma petersii, Salenocidaris varispina, Pourtalesia miranda, Homolampas fragilis, Linopneustes longispinus.

2990A – 415 fms. 11 species.
Caryometra alope, Goniopecten demonstrans, Nymphaster arenatus, Ophiacantha echinulata, Ophioconis miliaria, Amphiophiura metabula, Bathypectinura lacertosa, Ophiomusium lymani, Ophiernus adspersum, Salenocidaris varispina, Homolampas fragilis.

2990B – 415 fms. 7 species.
Cheiraster coronatus, Nymphaster arenatus, Circeaster occidentalis, Ophiernus adspersum, Salenocidaris varispina, Aceste bellidifera, Homolampas fragilis.

2991 – 475 fms. 9 species.
Goniopecten demonstrans, Psilaster squameus, Cheiraster coronatus, Pseudarchaster parelii, Nymphaster arenatus, Solaster caribbaeus, Ophiacantha echinulata, Bathypectinura lacertosa, Phormosoma placenta var. sigsbeei.

2991A – 475 fms. 7 species.
Goniopecten demonstrans, Psilaster squameus, Persephonaster spinulosus, Cheiraster coronatus, Zoroaster ackleyi, Ophiacantha mesembria, Phormosoma placenta var. sigsbeei.

2992 – 555 fms. 3 species.
Ceramaster grenadensis, Plinthaster dentatus, Salenocidaris varispina.

2992A – 555 fms. 4 species.
Persephonaster spinulosus, Nymphaster arenatus, Plinthaster dentatus, Zoroaster ackleyi.

2993 – 580 fms. 4 species.
Odontaster hispidus, Henricia antillarum, Zoroaster ackleyi, Ophiosphalma serratum.

2994 – 565-585 fms. 2 species.
Plutonaster bifrons, Plutonaster intermedius.

2995 – 370-605 fms. 11 species.
Cheiraster coronatus, Ceramaster grenadensis, Nymphaster arenatus, Peltaster hebes, Lophaster furcifer, Asteroschema arenosum, Ophioplinthaca dipsacos, Amphiophiura metabula, Ophiomusium lymani, Ophiernus adspersum, Salenocidaris varispina.

2996 – 470-665 fms. 3 species.
Plinthaster dentatus, Henricia antillarum, Ophiacantha echinulata.

2998A – 365 fms. 1 species.
Homolampas fragilis.

2999 – 145-230 fms. 17 species.
Endoxocrinus parrae, Neocomatella pulchella, Horaeometra duplex, Crinometra granulifera, Crinometra insculpta, Cheiraster coronatus, Pseudarchaster parelii, Zoroaster ackleyi, Ophiomyxa tumida, Ophiophrixus quadrispinosus, Asteronyx loveni, Astrospartus mucronatus, Ophiomitra valida, Ophiomusium validum, Araeosoma belli, Conolampas sigsbei, Linopneustes longispinus. A specimen of Meoma ventricosa has a label with this station number but was probably from shallow water in Matanzas Bay.

3000 – 170-255 fms. 11 species.
Crinometra insculpta, Paragonaster grandis, Nymphaster subspinosus, Henricia microspina, Pteraster rugosus, Zoroaster ackleyi, Mammaster sigsbei, Ophiomyxa tumida, Ophiomusium validum, Clypeaster cyclopilus, Palaeopneutes cristatus.

3004 – 185-205 fms. 1 species.
Coronaster briareus.

3302 – 230 fms. 18 species.
Neocrinus decorus, Endoxocrinus parrae, Neocomatella pulchella, Mediaster pedicellaris, Astroceramus brachyactis, Ophidiaster alexandri, Pteraster rugosus, Asteroschema brachiatum, Asteroschema laeve, Astrogomphus vallatus, Ophiochondrus gracilis, Sigsbeia murrhina, Ophiomitra valida, Ophiotreta lineolata, Cidaris blakei, Stylocidaris affinis, Aspidodiadema jacobyi, Linopneustes longispinus.

3303 – 260 fms. 27 species.
Neocrinus decorus, Endoxocrinus parrae, Endoxocrinus prionodes, Neocomatella pulchella, Stylometra spinifera, Horaeometra duplex, Crinometra granulifera, Crinometra insculpta, Pseudarchaster parelii, Echinaster modestus, Henricia antillarum, Asteroschema intectum, Asteroschema laeve, Asteroschema oligactes, Astrogomphus vallatus, Asteroporpa pulchra, Sigsbeia murrhina, Ophiomitra valida, Ophiotreta lineolata, Ophiarachnella petersi, Stylocidaris affinis, Histocidaris nuttingi, Aspidodiadema jacobyi, Salenia pattersoni, Clypeaster cyclopilus, Conolampas sigsbei, Palaeotropus josephinae.

3305 – 330 fms. 12 species.
Trichometra cubensis, Circeaster occidentalis, Ophiochondrella squamosa, Ophiacantha echinulata, Ophiacantha mesembria, Ophioplinthaca dipsacos, Amphiophiura metabula, Bathypectinura lacertosa, Ophiomusium lymani, Ophiosphalma serratum, Ophiernus adpersum, Cidaris micans.

3306 – 330 fms. 6 species.
Peltaster planus, Ophiacantha echinulata, Ophioplinthaca dipsacos, Ophiomusium lymani, Ophiosphalma serratum, Ophiernus adspersum.

3384 – 290 fms. 4 species.
Amphiophiura oedignatha, Ophiomusium microporum, Aspidodiadema jacobyi, Linopneustes longispinus.

3385 – 290 fms. 6 species.
Caryometra atlantidis, Ophiura acervata, Amphiophiura oedignatha, Ophiomusium microporum, Cidaris blakei, Phormosoma placenta var. sigsbei.

3386 – 220 fms. 17 species.
Caryometra atlantidis, Prionaster elegans, Astropecten articulatus, Luidia barbadensis, Cheiraster coronatus, Pseudarchaster parelii, Ophioprium cervicorne, Ophiura acervata, Ophiomusium validum, Cidaris blakei, Aspidodiadema jacobyi, Araeosoma belli, Archaeopneustes hystrix, Palaeopneustes cristatus, Schizaster orbignyanus, Brissopsis atlantica, Linopneustes longipinus.

3387 – 245 fms. 10 species.
Cheiraster coronatus, Anthenoides peircei, Mammaster sigsbeei, Pedicellaster pourtalesi, Ophiacantha scutata, Ophiura acervata, Ophiomusium microporum, Ophiomusium stellatum, Ophiomusium validum, Brissopsis atlantica.

3388 – 255 fms. 12 species.
Crinometra insculpta, Luidiaster mixtus, Tessellaster notabilis, Mammaster sigsbeei, Pedicellaster pourtalesi, Ophioprium cervicorne, Ophiura acervata, Ophiomusium validum, Ophiomusium microporum, Cidaris blakei, Schizaster orbignyanus, Brissopsis atlantica.

3389 – 220 fms. 8 species.
Caryometra atlantidis, Astropecten articulatus, Luidia barbadensis, Cheiraster coronatus, Ophiura acervata, Ophiomusium validum, Aspidodiadema jacobyi, Archaeopneustes hystrix.

3390 – 180 fms. 4 species.
Pseudarchaster parelii, Ophiura acervata, Araeosoma belli, Archaeopneustes hystrix.

3391 – 220 fms. 9 species.
Caryometra atlantidis, Prionaster elegans, Cheiraster coronatus, Pseudarchaster parelii, Anthenoides peircei, Ophiura acervata, Ophiomusium validum, Araeosoma belli, Brissopsis atlantica.

3392 – 225 fms. 11 species.
Caryometra atlantidis, Prionaster elegans, Astropecten articulatus, Cheiraster coronatus, Luidiaster mixtus, Ophiomyxa tumida, Ophiura acervata, Ophiomusium validum, Cidaris blakei, Aspidodiadema jacobyi, Brissopsis atlantica.

3393 – 220 fms. 9 species.
Caryometra atlantidis, Luidiaster mixtus, Ophiomyxa tumida, Ophiura acervata, Ophiomusium stellatum, Ophiomusium validum, Aspidodiadema jacobyi, Araesoma belli, Palaeopneustes cristatus.

3394 – 200 fms. 6 species.
Caryometra atlantidis, Anthenoides peircei, Henricia microspina, Ophiomyxa tumida, Ophiura acervata, Ophiomusium validum.

3396 – 180 fms. 5 species.
Astropecten articulatus, Anthenoides peircei, Ophiura acervata, Araeosoma belli, Clypeaster euclastus.

3397 – 180 fms. 4 species.
Echinaster sentus, Stylocidaris affinis, Araeosoma belli, Archaeopneustes hystrix.

3398 – 180 fms. 4 species.
Pseudarchaster parelii, Araeosoma belli, Archaeopneustes hystrix, Palaeopneustes cristatus.

3399 – 180 fms. 3 species.
Luidia barbadensis, Pseudarchaster parelii, Araeosoma belli.

3400 – 180 fms. 9 species.
Astropecten articulatus, Cheiraster coronatus, Pseudarchaster parelii, Ophiura acervata, Ophiopaepale goesiana, Ophiopyren longispinus, Araeosoma belli, Araeosoma fenestratum, Archaeopneustes hystrix.

3401 – 235 fms. 6 species.
Caryometra atlantidis, Luidia barbadensis, Cheiraster coronatus, Ophiura acervata, Ophiomusium validum, Brissopsis atlantica.

3402 – 230 fms. 4 species.
Amphitarsus mirabilis, Ophiura acervata, Amphiophiura oedignatha, Ophiomusium validum.

3403 – 210 fms. 4 species.
Pseudarchaster parelii, Ophiomusium validum, Araeosoma belli, Brissopsis atlantica.

3404 – 215 fms. 7 species.
Caryometra atlantidis, Ophiomastus secundus, Ophiura lepida, Ophiomusium validum, Ophiosphalma serratum, Araeosoma belli, Linopneustes longispinus.

3405 – 235 fms. 8 species.
Caryometra atlantidis, Prionaster elegans, Ophiura acervata, Ophiomusium validum, Cidaris blakei, Araeosoma belli, Schizaster orbignyanus, Brissopsis atlantica.

3406 – 200 fms. 4 species.
Caryometra alope, Cheiraster coronatus, Pseudarchaster parelii, Araeosoma belli.

3407 – 200 fms. 1 specie.
Ophiura acervata.

3408 – 208 fms. 6 species.
Prionaster elegans, Cheiraster coronatus, Anthenoides peircei, Henricia microspina, Ophioprium cervicorne, Palaeopneustes cristatus.

3409 – 200 fms. 3 pecies.
Prionaster elegans, Pseudarchaster parleii, Araeosoma belli.

3410 – 260 fms. 9 species.
Prionaster elgeans, Cheiraster coronatus, Mammaster sigsbeei, Ophiacantha scutata, Ophiura acervata, Ophiomusium validum, Cidaris blakei, Schizaster orbignyanus, Brissopsis atlantica.

3411 – 260 fms. 8 species.
Prionaster elegans, Cheiraster coronatus, Ophiacantha scutata, Ophiomusium validum, Cidaris blakei, Araeosoma belli, Schizaster orbignyanus, Brissopsis atlantica.

3412 – 235 fms. 7 species.
Compsometra nuttingi, Caryometra atlantidis, Cheiraster coronatus, Ophiomusium validum, Cidaris blakei, Araeosoma belli, Brissopsis atlantica.

3413 – 215 fms. 8 species.
Caryometra atlantidis, Luidia barbadensis ,Luidiaster mixtus, Pseudarchaster parelii, Anthenoides peircei, Araeosoma belli, Brissopsis atlantica, Linopneustes longispinus.

3414 – 230 fms. 5 species.
Pseudarchaster parelii, Ophiomyxa tumida, Araeosoma belli, Brissopsis atlantica, Linopneustes longispinus.

3415 – 210 fms. 3 species.
Araeosoma belli, Brissopsis atlantica, Linopneustes longispinus.

3416 – 200 fms. 4 species.
Caryometra atlantidis, Pseudarchaster parelii, Ophiomusium validum, Araeosoma belli.

3417 – 200 fms. 5 species.
Astropecten articulatus, Pseudarchaster parelii, Araeosoma belli, Araeosoma fenestratum, Linopneustes longispinus.

3418 – 195 fms. 3 species.
Anthenoides peircei, Araeosoma belli, Palaeopneustes cristatus.

3419 – 180 fms. 3 species.
Ophiura acervata, Araeosoma belli, Palaeopneustes cristatus.

3420 – 190 fms. 3 species.
Astropecten articulatus, Pseudarchaster parelii, Araeosoma belli.

3421 – 235 fms. 4 species.
Caryometra atlantidis, Pseudarchaster parelii, Ophiomyxa tumida, Aspidodiadema jacobyi.

3422 – 235 fms. 3 species.
Astropecten articulatus, Anthenoides peirscei, Amphitarsus mirabilis.

3423 – 245 fms. 5 species.
Luidiaster mixtus, Pseudarchaster parelii, Henricia micropsina, Ophiomusium validum, Echinocyamus grandiporus.

3425 – 250 fms. 2 species.
Crinometra insculpta, Ophiomusium validum.

3427 – 240 fms. 4 species.
Caryometra atlantidis, Luidiaster mixtus, Henricia microspina, Araeosoma belli.

3428 – 240 fms. 6 species.
Pseudarchaster parelii, Henricia microspina, Pedicellaster pourtalesi, Ophiomusium validum, Hemiaster expergitus, Brissopsis atlantica.

3430 – 235 fms. 2 species.
Crinometra insculpta, Ophiomusium validum.

3431 – 245 fms. 5 species.
Crinometra insculpta, Henricia microspina, Mammaster sigsbeei, Pedicellaster pourtalesi, Linopneustes longispinus.

3432 – 250 fms. 4 species.
Crinometra insculpta, Prionaster elegans, Cidaris blakei, Plethotaenia spatangoides.

3434 – 260 fms. 8 species.
Crinometra insculpta, Prionaster elegans, Mammaster sigsbeei, Ophiacamax fasciculata, Ophiomusium validum, Stylocidaris affinis, Plethotaenia spatangoides, Linopneustes longispinus.

3435 – 255 fms. 9 species.
Neocrinus blakei, Crinometra insculpta, Caryometra monilicirra, Henricia microspina, Mammaster sigsbeei, Ophiacantha scutata, Ophiotreta sertata, Stylocidaris affinis, Plethotaenia spatangoides.

3436 – 255 fms. 17 species.
Crinometra insculpta, Prionaster elegans, Nymphaster subspinosus, Henricia antillarum, Pteraster militarioides, Mammaster sigsbeei, Ophiomyxa tumida, Asteroschema laeve, Asteroschema oligactes, Ophiacantha scutata, Ophioprium cervicorne, Ophiotreta sertata, Ophiura acervata, Ophiomusium validum, Ophiomusium microporum, Cidaris blakei, Plethotaenia spatangoides.

3437 – 260 fms. 16 species.
Horaeometra duplex, Prionaster elegans, Cheiraster mirabilis, Nymphaster arenatus, Nymphaster subspinosus, Henricia antillarum, Zoroaster ackleyi, Mammaster sigsbeei, Pedicellaster pourtalesi, Ophiacantha scutata, Ophiura acervata, Amphiophiura oedignatha, Ophiomusium lymani, Ophiomusium microporum, Ophioceramis rugosa, Linopneustes longispinus.

3438 – 265 fms. 22 species.
Endoxocrinus prionodes, Neocomatella pulchella, Crinometra insculpta, Prionaster elegans, Cheiraster mirabilis, Luidiaster mixtus, Nymphaster arenatus, Nymphaster subspinosus, Henricia antillarum, Mammaster sigsbeei, Pedicellaster pourtalesi, Ophiogeron granulatus, Asteroschema laeve, Astrogomphus vallatus, Ophiacantha pentacrinus, Ophiacantha scutata, Ophiomitra valida, Ophiotreta lineolata, Ophiomusium lymani, Ophiomusium testudo, Ophiozonella marmorea, Aspidodiadema jacobyi.

3439 – 295 fms. 15 species.
Endoxocrinus parrae, Cheiraster mirabilis, Nymphaster arenatus, Nymphaster subspinosus, Henricia microspina, Pteraster militarioides, Ophiogeron granulatus, Asteroschema laeve, Ophiocreas spinulosum, Ophiacantha scutata, Ophiomitra valida, Ophiocamax fasciculata, Ophiura falcifera, Amphiophiura oedignatha, Ophiosphalma dyscritum.

3440 – 310 fms. 1 species.
Cidaris blakei.

3442 – 335 fms. 8 species.
Persephonaster echinulatus, Cheiraster mirabilis, Asterias crassispina, Amphiophiura oedignatha, Ophiomusium eburneum, Ophiomusium lymani, Cidaris blakei, Stylocidaris affinis.

3443 – 325 fms. 11 species.
Persophonaster echinulatus, Cheiraster mirabilis, Nymphaster arenatus, Nymphaster subspinosus, Henricia antillarum, Mammaster sigsbeei, Ophiocamax fasciculata, Ophiomusium eburneum, Ophiomusium lymani, Ophiosphalma dyscritum, Linopneustes longispinus.

3444 – 320 fms. 10 species.
Cheiraster mirabilis, Nymphaster subspinosus, Plinthaster dentatus, Ophiocamax fasciculata, Ophiura falcifera, Ophiomusium lymani, Ophiosphalma armigerum, Ophiosphalma dyscritum, Ophioceramis rugosa, Ophiernus adspersum.

3445 – 330 fms. 11 species.
Persephonaster echinulatus, Cheiraster mirabilis, Plinthaster dentatus, Ophiacantha pentacrinus, Ophiacantha scutata, Ophiocamax fasciculata, Ophiochiton grandis, Ophiomusium lymani, Ophiosphalma dyscritum, Ophioceramis rugosa, Ophiernus adspersum.

3446 – 360 fms. 9 species.
Henricia antillarum, Pteraster militarioides, Ophiacantha echinulata, Ophioplinthaca dipsacos, Ophiocamax fasciculata, Amphiura otteri, Ophiomusium lymani, Ophiosphalma dyscritum, Ophiernus adspersum.

3447 – 375 fms. 11 species.
Persephonaster echinulatus, Cheiraster mirabilis, Nymphaster arenatus, Henricia antillarum, Ophiacantha echinulata, Ophiocamax fasciculata, Ophiomusium eburneum, Ophiomusium lymani, Ophiosphalma serratum, Ophiosphalma dyscritum, Aspidodiadema jacobyi.

3448 – 380 fms. 9 species.
Nymphaster arenatus, Nymphaster subspinosus, Henricia antillarum, Pteraster militarioides, Ophiacantha echinulata, Ophiocamax fasciculata, Ophiomusium lymani, Ophiosphalma serratum, Ophiosphalma dyscritum.

3449 – 390 fms. 13 species.
Persephonaster echinulatus, Cheiraster mirabilis, Pseudarchaster concinnus, Ceramaster grenadensis, Nymphaster arenatus, Henricia antillarum, Ophiocamax fasciculata, Ophiosphalma serratum, Ophiosphalma dyscritum, Ophiernus adspersum, Araeosoma belli, Salenocidaris varispina, Homolampas fragilis.

3450 – 390 fms. 8 species.
Pseudarchaster concinnus, Ceramaster grenadensis, Henricia microspina, Ophiocamax fasciculata, Ophiosphalma serratum, Echinocyamus grandiporus, Pourtalesia miranda, Homolampas fragilis.

3451 – 405 fms. 7 species.
Cheiraster coronatus, Pseudarchaster concinnus, Nymphaster arenatus, Henricia antillarum, Pteraster militarioides, Ophiomusium eburneum, Pourtalesia miranda.

3454 – 600 fms. 2 species.
Amphiophiura metabula, Salenocidaris varispina.

3456 – 575 fms. 2 species.
Ophiernus adspersum, Phormosoma placenta var. sigsbei.

3457 – 550 fms. 2 species.
Persephonaster spinulosus, Plinthaster dentatus.

3459 – 500 fms. 15 species.
Goniopecten demonstrans, Cheiraster coronatus, Cheiraster mirabilis, Nymphaster arenatus, Henricia antillarum, Ophioplinthaca dipsacos, Ophiochiton grandis, Amphiophiura metabula, Ophiosphalma monoplax, Ophiopyren longispinus, Histocidaris sharreri, Phormosoma placenta var. sigsbei, Salenocidaris varispina, Habrocidaris scutata, Homolampas fragilis.

3460 – 240 fms. 1 species.
Brissopsis atlantica.

3463 – 230 fms. 9 species.
Neocomatella pulchella, Caryometra alope, Asteroschema brachiatum, Asteroschema laeve, Ophiomitra valida, Ophiomusium validum, Stylocidaris affinis, Aspidodiadema jacobyi, Conolampas sigsbei.

3464 – 200 fms. 1 species.
Aspidodiadema jacobyi.

3465 – 175 fms. 25 species.
Endoxocrinus parrae, Neocomatella pulchella, Stylometra spinifera, Horaeometra duplex, Crinometra granulifera, Cheriaster coronatus, Henricia microspina, Pteraster rugosus, Zoroaster ackleyi, Asteroschema intectum, Asteroschema laeve, Asteroschema oligactes, Asteroporpa pulchra, Astros-

partus mucronatus, Ophiacantha hirsuta, Ophiacantha pentacrinus, Ophiomitra valida, Ophiarachnella petersi, Ophiomusium acuferum, Ophiomusium validum, Stylocidaris affinis, Aspidodiadema jacobyi, Phormosoma sigsbei, Araeosoma belli, Conolampas sigsbei.

3466 – 200 fms. 11 species.

Neocomatella pulchella, Stylometra spinifera, Horaeometra duplex, Crinometra insculpta, Asteroschema intectum, Ophiacantha hirsuta, Ophiomitra valida, Ophiomusium validum, Ophiomusium microporum, Stylocidaris affinis, Aspidodiadema jacobyi.

3467 – 215 fms. 15 species.

Neocrinus decorus, Endoxocrinus parrae, Horaeometra duplex, Crinometra insculpta, Henricia microspina, Zoroaster ackleyi, Asteroschema oligactes, Ophiomitra valida, Ophiomusium validum, Cidaris blakei, Stylocidaris affinis, Aspidodiadema jacobyi, Clypeaster cyclopilus, Conolampas sigsbei, Plethotaenia spatangoides.

3468 – 375 fms. 6 species.

Persephonaster echinulatus, Ophiacantha echinulata, Ophiacantha scutata, Ophiocamax fasciculata, Amphiophiura metabula, Ophiomusium lymani.

3469 – 425 fms. 9 species.

Caryometra alope, Pteraster stoibe, Ophiacantha echinulata, Ophioplinthaca dipsacos, Ophiernus adspersum, Araeosoma fenestratum, Salenocidaris varispina, Archaeopneustes hystrix, Brissopsis atlantica.

3470 – 610 fms. 1 species.

Ophioplinthaca dipsacos.

3472 – 510 fms. 2 species.

Plinthaster dentatus, Amphiophiura metabula.

3474 – 490 fms. 6 species.

Goniopecten demonstrans, Ceramaster grenadensis, Nymphaster arenatus, Circeaster occidentalis, Ophiernus adspersum, Cidaris blakei.

3475 – 400 fms. 6 species.

Ophiacantha echinulata, Amphiophiura metabula, Amphiophiura oedignatha, Ophiomusium eburneum, Ophiomusium lymani, Echinocyamus grandiporus.

3476 – 360 fms. 2 species.

Amphiophiura oedignatha, Histocidaris nuttingi.

3478 – 240 fms. 28 species.

Endoxocrinus parrae, Neocomatella pulchella, Horaeometra duplex, Crinometra granulifera, Crinometra insculpta, Prionaster elegans, Astropecten articulatus, Cheiraster coronatus, Rosaster alexandri, Pteraster rugosus, Zoroaster ackleyi, Ophiomyxa tumida, Asteroschema intectum, Asteronyx loveni, Astrogomphus vallatus, Asteroporpa pulchra, Ophiacantha hirsuta, Ophiomitra valida, Ophiomusium acuferum, Ophiomusium testudo, Ophiomusium validum, Cidaris blakei, Stylocidaris affinis, Aspidodiadema jacobyi, Araeosoma belli, Clypeaster cyclopilus, Conolampas sigsbei, Linopneustes longispinus.

3479 – 210 fms. 20 species.

Neocrinus decorus, Neocomatellá pulchella, Horaeometra duplex, Cheiraster coronatus, Rosaster alexandri, Linckia bouvieri, Henricia microspina, Pteraster rugosus, Zoroaster ackleyi, Asteroschema intectum, Asteroschema laeve, Asteroschema oligactes, Ophiomitra valida, Ophiotreta lineolata, Ophiomusium validum, Stylocidaris affinis, Aspidodiadema jacobyi, Araeosoma fenestratum, Clypeaster cyclopilus, Conolampas sigsbei.

3480 – 200 fms. 23 species.

Neocrinus decorus, Endoxocrinus parrae, Neocomatella pulchella, Horaeometra duplex, Luidiaster mixtus, Pseudarchaster parelii, Rosaster alexandri, Anthenoides peircei, Ophidiaster alexandri, Pteraster rugosus, Zoroaster ackleyi, Ophiomyxa tumida, Asteroschema intectum, Asteroschema oligactes, Astrogomphus vallatus, Asteroporpa pulchra, Ophiacantha hirsuta, Ophiomitra valida, Stylocidaris affinis, Aspidodiadema jacobyi, Araeosoma belli, Conolampas sigsbei, Linopneustes longispinus.

3482 – 190 fms. 30 species.

5 crinoids: Neocrinus decorus, Endoxocrinus parrae, Stylometra spinifera, Crinometra granulifera, Crinometra insculpta.

6 asteroids; one not taken elsewhere: Luidiaster mixtus, Rosaster alexandri, Anthenoides peircei, Henricia microspina, Henricia sexradiata, Zoroaster ackleyi.

10 ophiurans; one new to science, and not taken elsewhere: Asteroschema intectum, Asteroschema laeve, Asteroschema oligactes, Asteroporpa pulchra, Ophiacantha scutata, Ophiomitra valida, Ophiotreta lineolata, Ophioplax pardalis, Ophiarachnella petersi, Ophiomusium testudo.

9 echini: Stylocidaris affinis, Aspidodiadema jacobyi, Araeosoma belli, Salenia pattersoni, Coelopleurus floridanus, Conolampas sigsbei, Archaeopneustes hystrix, Palaeotropus josephinae, Linopneustes longispinus.

3483 – 285 fms. 17 species.

Cheiraster coronatus, Cheiraster mirabilis, Nymphaster arenatus, Zoroaster ackleyi, Pedicellaster pourtalesi, Ophiogeron granulatus, Asteroschema oligactes, Ophiocreas spinulosum, Astrospartus mucronatus, Ophiacantha scutata, Ophiomitra valida, Ophiotreta lineolata, Ophiomusium lymani, Ophiomusium stellatum, Ophiosphalma dyscritum, Ophiernus adspersum, Plethotaenia spatangoides.

3485 – 385 fms. 8 species.

Persephonaster echinulatus, Nymphaster arenatus, Henricia antillarum, Ophiacantha echinulata, Ophiomusium eburneum, Ophiosphalma monoplax, Ophiosphalma serratum, Ophiernus adspersum.

3487 – 535 fms. 2 species.

Ophiocamax fasciculata, Ophiomusium eburneum.

3490 – 250 fms. 2 species.

Mammaster sigsbei, Araeosoma belli.

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Nat. size.

FIG. 1. *Psilaster squameus* sp. nov. Page 17.
,, 2. *Luidiaster dubius* sp. nov. Page 30.

¾ Nat. size

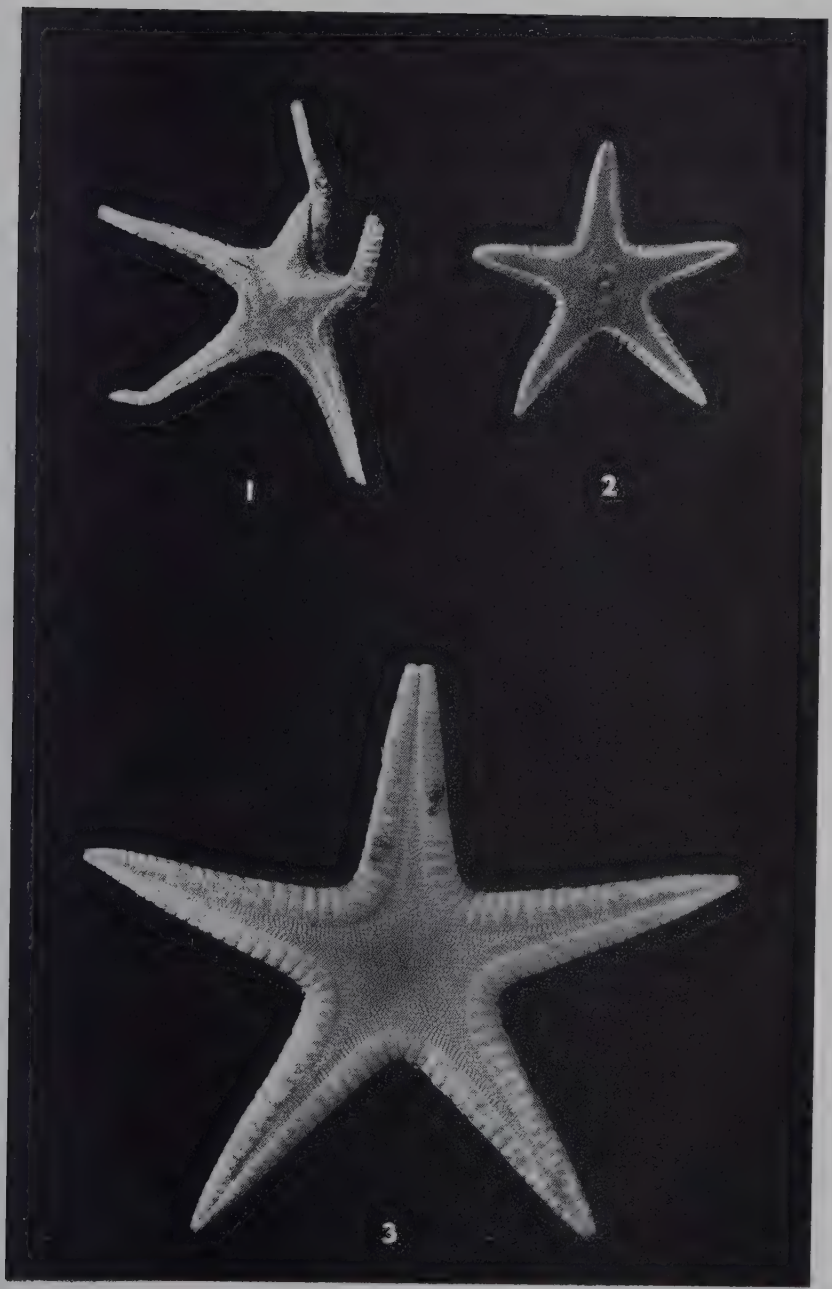

FIG. 1. *Perscphonaster lep'actis* sp. nov. Page 22. Nat. size.
,, 2. *Persephonaster echinulatus* sp. nov. Page 20. Nat. size.
,, 3. *Persephonaster spinulosus* sp. nov. Page 23. ¾ Nat. size.

FIG. 1. *Paragonaster grandis* sp. nov. Page 32.
,, 2. *Circeaster occidentalis* sp. nov. Page 46.
2/3 Nat. size.

FIG. 1. *Tessellaster notabilis* sp. nov. Page 37.
„ 2. *Ophidiaster pinguis* sp. nov. Page 51.

2/3 Nat. size.

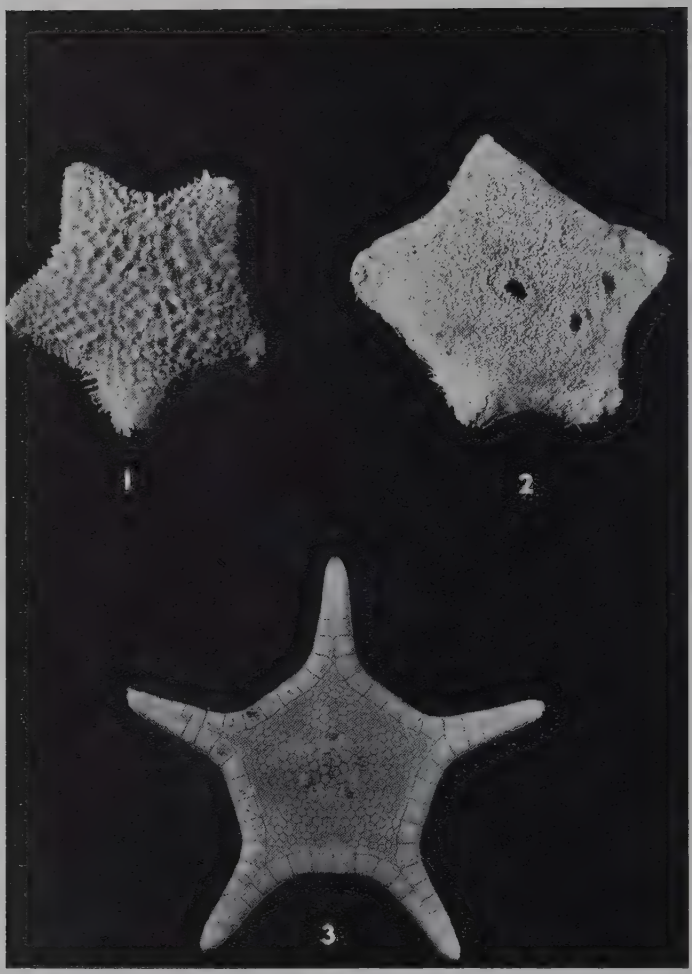

FIG. 1. *Pteraster rugosus* sp. nov. Page 61.
,, 2. *Pteraster stoibe* sp. nov. Page 63.
,, 3. *Astroceramus brachyactis* sp. nov. Page 45.

Slightly enlarged.

Asterias crassispina sp. nov. Page 68.
4 × Nat. size.

Amphitarsus mirabilis sp. nov. Page 84.

FIG. 1. Upper surface.
„ 2. Lower surface.
5 × Nat. size.

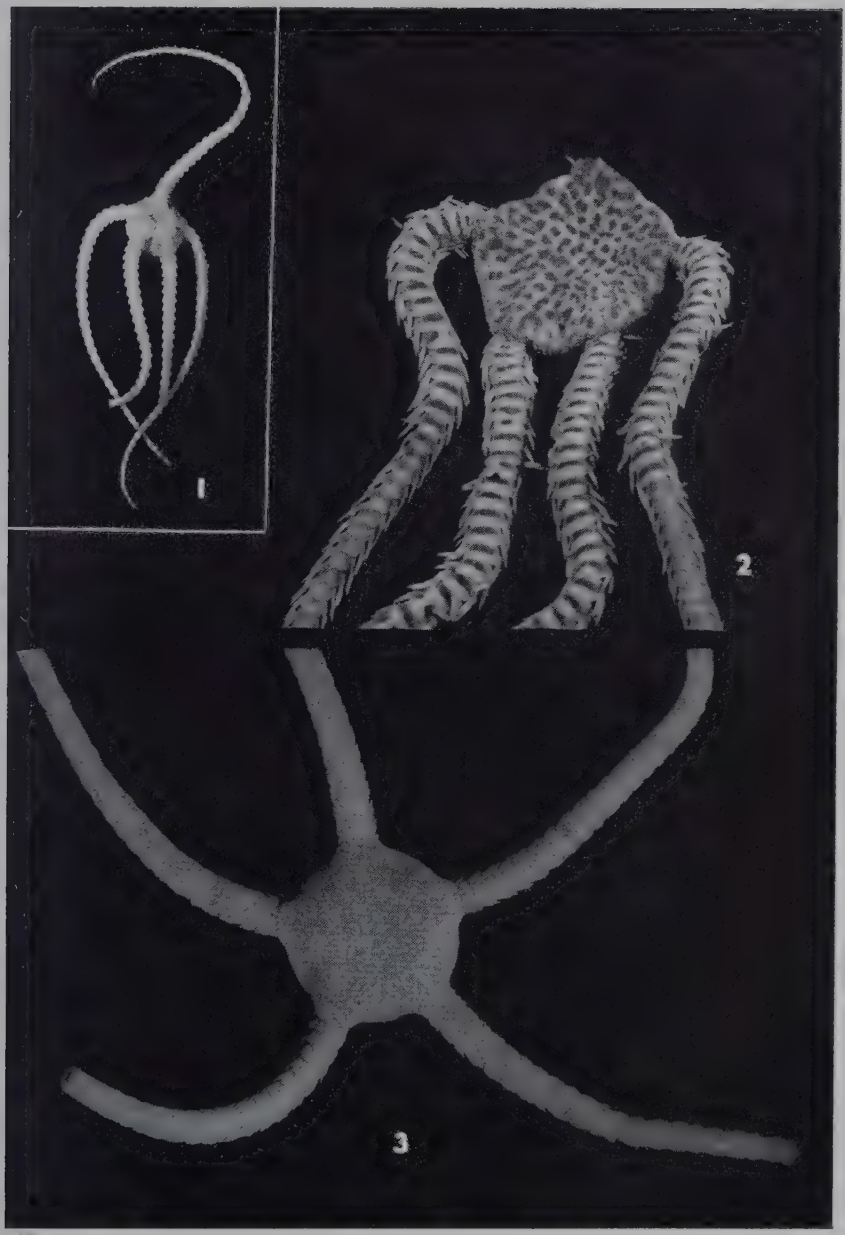

FIG. 1. *Ophiosphalma dyscritum* sp. nov. Page 101.
Nat. size.

,, 2. *Ophioplax pardalis* sp. nov. Page 87.
3 × Nat. size.

,, 3. *Ophiozonella granulifera* sp. nov. Page 104.
2 × Nat. size.

FIG. 1. *Clypeaster cyclopilus* sp. nov. Page 118.

„ 2. *Clypeaster euclastus* sp. nov. Page 120.

½ Nat. size.

PLANKTON STUDIES. IV. GEORGES BANK*

By Gordon A. Riley

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and

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* Joint contribution from the Woods Hole Oceanographic Institution (No. 287) and the Bingham Oceanographic Foundation, Yale University.

INTRODUCTION

This paper is a study of the quantitative aspects of the phytoplankton of Georges Bank in relation to the environmental factors which influence its growth and distribution. It is part of a general survey of Georges Bank by several investigators, the purpose of which is to obtain needed information about the spawning and larval development of the haddock. Secondarily, the paper forms an important part of the "Plankton Studies" series. As a moderately shallow, oceanic region in temperate waters, the Bank presents many features which are interesting in comparison with the shallow coastal waters of Long Island Sound and the tropical shallows of the Tortugas region.

The Georges Bank region has previously been subjected to both physical and biological investigations as part of the Gulf of Maine project of the Woods Hole Oceanographic Institution. Some of these papers which bear directly on the present work and are mentioned later in the text are Bigelow (1926, 1927) and Rakestraw (1933). Two papers which unfortunately came to the writer's attention too late to be discussed in the main body of the report are Bigelow, Lillick, and Sears (1940) and Lillick (1940). Since they extend over a period of several years and cover a somewhat larger area than the Georges Bank project, they are extremely important in providing background and perspective for the present investigation. The latter, as stated before, is designed to facilitate quantitative analyses of the relations of the organisms with their environment. It therefore requires somewhat different methods, and its results are not exactly comparable to the previous investigations. In general, however, it may be said that the results are in agreement as to the nature and time relations of the seasonal cycle and the relative quantities of plankton in the different areas. More detailed comparisons await a subsequent paper by Sears, which enumerates the individual species and draws the two projects into a unified whole.

The author is indebted to Mr. Albert E. Parr, Mr. G. Evelyn Hutchinson, and Miss Mary Sears for reading and criticizing the manuscript, to Mr. C. O'D. Iselin for data on salinities, and to Mr. H. J. Turner for assistance on one of the cruises.

METHODS

Samples were collected at depths of 1, 10, 30, 50, 100, and 200 meters, or as many of these as the depth of water at the station permitted. Due to the quantity of water required for the analyses it was necessary to use two Nansen bottles at each depth. Thus the ten meter sample, for example, was a mixed sample obtained from ten and eleven meters. At the surface only one bottle was used, and the remainder of the water was hauled up with a bucket.

Analyses of plant pigments were made according to the method of Harvey (1934). The plankton for this determination was obtained by filtering water through a Whatman No. 2 paper. Generally one liter of water was sufficient for the test; occasionally two or three liters were used. The plant pigment extract from the surface plankton was also used for the separation and measurement of its chlorophyll content (Riley, 1938).

Phosphates were determined by the Atkins-Déniges method as modified by Cooper (1938). Atkins' (1932) method was used for nitrate. It was frequently impossible to determine the nitrate and phosphate immediately after the samples were collected. They were generally analyzed within twelve hours, and always within twenty-four hours of collection, but this unfortunate delay may have caused some error in the results.

Water from each depth was analyzed for oxygen by the Winkler method. Experimental estimates of the photosynthetic activity of the surface plankton were made by suspending light and dark bottles of surface water in a tub on deck. The water in the tub was changed frequently to maintain an even temperature. After twenty-four hours of exposure the oxygen was determined. The difference between the light and dark bottles was assumed to indicate the photosynthesis of the phytoplankton. The difference between the surface water at the beginning of the experiment and the final determination of the oxygen content of the dark bottle constituted the respiration of the entire plankton association. During the September cruise the consumption and regeneration of nitrate in the experimental bottles were also determined. Since only one milliliter of water is required for the nitrate analysis, it was possible to make the determination on the oxygen bottle, removing one milliliter of water from the bottle immediately before adding the oxygen reagents.

Between September, 1939, and July, 1940, six cruises were made to Georges Bank. The stations were distributed as evenly as possible over the shallow part of the bank and extended into deep water on all sides. Twenty-six stations were made between September 7 and 16, eleven between January 4 and 11, fifteen between March 25 and April 2, seventeen between April 17 and 26, twenty-one between May 9 and 16, and thirty between June 19 and 26. Thus, in all, one hundred-twenty stations were examined. Thirty-two of these were in shallow water, which permitted analyses only at the surface and at depths of ten and thirty meters. Sixty-three were deep enough to permit additional analyses at the fifty-meter level; twenty-five had depths of more than one hundred meters and of these twelve were deep enough for two-hundred-meter samples.

DESCRIPTIVE SECTION

Physical Basis of the Survey

Georges Bank lies roughly within Lat. 40° 40′ and 42° 10′ N. and W., Long. 66° and 69°. Its general topographical features are described by Bigelow (1927) as follows: "the length of Georges Bank, from the deepest trough of the South Channel to the 50-fathom contour on the slope of the Eastern Channel is about 140 miles, with a greatest breadth of about 80 miles from north to south between the 50-fathom contours. . . . In round figures, the area of Georges Bank is 10,000 square miles. . . . On the southern and eastern parts the depths range, in round numbers, from 30 to 40 fathoms (55 to 73 meters). Over its northwestern one-third the water is shallower, with a considerable but much broken area shallower than 20 fathoms (37 meters), culminating in the dangerous 'Georges' and Cultivator Shoals, the former with only 2½ to 10 fathoms (4½ to 18 meters), the latter with 3 to 10 fathoms (6 to 18 meters)."

The general features of the temperature distribution on Georges Bank are shown in Table I, in which are recorded the mean values for each cruise. The March minimum is characteristic of the area, and the September average is approximately the same as the summer values given by Bigelow (1927). Considerable vertical turbulence occurred during January, March and April to a depth of 100 m. or more. During the remainder of the cruises there was a fairly well established discontinuity layer in areas where the depth was greater than about 50 to 70 m.

TABLE I

MEAN TEMPERATURES ON GEORGES BANK

Depth	*Sept.*	*Jan.*	*Mar.*	*Apr.*	*May*	*June*
1	16.480	4.596	2.607	3.854	5.600	10.617
10	16.210	4.608	2.571	3.790	5.258	10.158
30	13.155	4.702	2.643	3.801	4.747	8.325
50	9.931	5.138	3.078	3.892	4.442	7.027
100	7.619	8.453	7.558	6.740	6.805	8.923
200	8.863	8.015	6.540	7.490	——	11.415

The currents in general take the form of clockwise eddies, one around the shallowest part of the bank and another around the outside edge, although occasionally during the winter or spring water flows across the bank from northwest to southeast (Bigelow, 1927; Walford, 1938).

The Measurement of Phytoplankton

More than half a century of plankton investigations has produced no universally satisfactory method of measuring plankton. The centrifuge, the filter, and quantitative net collections have solved the sampling problem. Accuracy in sampling methods, however, solves nothing if the measurement of the sample is inaccurate. These measurements, which follow the inclination and the purposes of the investigator, tend to take two opposite extremes. On the one hand there is the simple enumeration of species which leads to studies on natural history, species competition and ecological succession, but is practically useless in determining the reactions of the plant association as a whole. On the other hand there are the quantitative measurements of chemical or physical attributes of the whole sample, which are important in studying the relations of the plant population with its environment, but which ignore individual species differences, not because the latter are not important, but because present methods are too crude to deal with them effectively.

For the present work, in which quantitative estimates are essential, Harvey's plant pigment method appears to be the most desirable. But to prove its applicability it is necessary to compare it with other standard methods. The present section is dedicated to that purpose.

At four or five stations on each cruise except the January one quali-

tative net collections were made by towing a No. 20 foot net at the surface for half an hour to an hour. A small part of the catch was used for an immediate measurement of plant pigments and chlorophyll. The remainder was preserved with mercuric chloride for counts and for determinations of dry weight, organic matter (difference on ignition), and ash.

Cell counts were made on fractions of the catch ranging from 0.025 to 2 ml., depending on the number of organisms present. Frequently a small volume of water was used to count the abundant organisms, and a larger volume for plants such as *Coscinodiscus excentricus*, which occurred in much smaller numbers but were important because of their large size. Measurements were made of fifty to one hundred individuals of each species. The average measurements were used to calculate the approximate cell volume by applying volume formulas which resembled the species in question. The measurements were made of each species in four different samples, and in cases where the four average volumes were found to differ significantly, the species was measured in all the samples. Thus it was possible to obtain an estimate of the total cell volume which, although subject to considerable error, particularly in fitting formulas to the cells, was far more accurate than other methods, such as the settling and displacement techniques, which are notoriously inaccurate for phytoplankton.

To determine the plankton weight, 100 ml. of the sample were strained through a piece of scrim in order to remove the larger animals. The remainder of the sample was washed several times with distilled water by allowing the plankton to settle, decanting the water and adding more. Finally the plankton was dried at 60° C. for two days, weighed, ignited and weighed again. In spite of the efforts to clean the sample, there remained many nauplii and bits of detritus of small size, that could not be separated from the phytoplankton by straining it. Thus, as measurements of phytoplankton weight, the results are subject to errors other than those commonly objected to in determining the difference on ignition. They can be partly obviated by statistical treatment of the data; however, as they would exist in any other quantitative chemical determination, it did not seem desirable to attempt more accurate measurements of chemical constituents.

The results of these various determinations are shown in Table II and the correlations of one type of measurement with another in Table III.

TABLE II

MEASUREMENTS OF NET PHYTOPLANKTON

(Expressed in terms of one milliliter of the catch)

Station	*Date*	*Plant Pigments (Harvey Units)*	*Chloro-phyll MG.*	*Number of cells*	*Cell Volume MM³*	*Dry Weight MG.*	*Organic Matter MG.*	*Ash MG.*
3660	9/13/39	0.20	.000076	150	0.028	0.110	0.092	0.018
3666	9/13 39	2.91	.00095	11200	0.660	0.343	0.237	0.106
3674	9/15 39	1.91	.00024	3500	0.499	0.262	0.251	0.011
3678	9/15/39	0.28	.00011	175	0.022	0.122	0.087	0.035
3679	9/16/39	0.27	.00014	440	0.020	1.110	0.072	0.038
3798	3/26/40	19.7	.0054	63000	2.560	1.450	0.891	0.559
3813	3/29/40	9.0	.0023	56000	3.571	0.917	0.423	0.494
3817	3/30/40	12.6	.0026	14000	3.099	0.785	0.318	0.467
3819	3/30/40	0.08	.000086	150	0.034	0.037	0.019	0.018
3824	4/2/40	8.6	.0037	10500	0.573	0.471	0.267	0.204
3828	4/18/40	11.7	.0041	7300	0.482	0.668	0.407	0.261
3839	4/20/40	8.5	.0024	11300	0.456	0.477	0.310	0.167
3844	4/25/40	12.5	.0032	6700	0.704	0.333	0.228	0.105
3850	4/26/40	2.97	.0012	1000	0.079	0.331	0.216	0.115
3860	5/10/40	0.63	.00057	420	0.127	0.147	0.084	0.063
3876	5/14/40	1.16	.00075	2700	0.065	0.113	0.079	0.034
3882	5/15/40	1.38	.00098	10000	0.101	0.160	0.124	0.036
3887	5/16/40	0.55	.00030	450	0.072	0.273	0.241	0.032
3954	6/24/40	1.65	.00029	5200	0.578	0.218	0.190	0.028
3956	6/24/40	6.72	.0011	4600	0.475	0.535	0.394	0.141
3959	6/25/40	12.7	.0024	85000	1.045	2.986	1.292	1.694
3964	6/26/40	19.6	.0021	17000	3.577	2.329	2.206	0.123
Mean		6.16	.001591	18750	0.856	0.599	0.383	0.216

TABLE III

CORRELATIONS OF NET PHYTOPLANKTON MEASUREMENTS

	Chloro-phyll	*Cell number*	*Volume*	*Dry wt.*	*Organic matter*	*Ash*
Plant pigments	.860	.508	.760	.761	.763	.516
Chlorophyll		.488	.518	.490	.406	.448
Cell number			.367	.564	.380	.635
Cell volume				.617	.655	.369
Dry weight					.904	.813
Organic matter						.486

The correlations of plant pigments with other measurements of phytoplankton are variable in quality but are all statistically significant. Moreover, they show a higher degree of relationship with the other variables than any other one type of determination. Thus it is evident that for quantitative purposes the plant pigment content is more nearly representative of plankton measurements in general than the other methods used here. From this standpoint the cell number is the poorest measurement. The reason is of course the great variation in the size of the cells. For example, Station 3828 had only about 7% of the number of cells that were obtained in the collection at Station 3839, but the former had a larger volume as well as plant pigment and organic matter content, etc. But at Station 3828 one of the major constituents was *Coscinodiscus excentricus* which had a volume nearly 400 times as great as *Chaetoceros decipiens*, the most important species at 3839.

It appears odd that the correlation of cell number with ash weight is the highest one obtained in any of the cell number calculations. This is probably due, however, to a relationship between ash and cell surface, due to the silica content of the diatoms' frustules, and the surface would of course be greatest in collections having a large number of small cells.

The very high correlations of dry weight with organic matter and ash are spurious; that is, a correlation is too high when one of the variables contains the other variable within itself.

Although the correlations are on the whole highly satisfactory, the ratios of the different measurements present puzzling problems, particularly in the relationships between volume and weight. The specific gravity of diatom cells is presumably somewhat greater than that of seawater under ordinary circumstances but not very much greater particularly when they have an adequate supply of storage products. The wet weight in milligrams is therefore slightly greater than the volume of the cells in cubic millimeters. Under these circumstances it seems unreasonable that the mean ratio of dry weight to wet weight should be as much as 70%, and that the individual samples should sometimes run above 100%, even though we know the percentages are maximal values.

It is evident, however, from inspection of the samples used for determining the weights that they were not composed entirely of

phytoplankton; on the contrary they contained some detritus and small animals. If we assume that the per cent dry weight of the phytoplankton is relatively constant, it can be determined by the regression equation of cell volume on dry weight. This equation is

$$DW = .392\,V + .263 \qquad (1)$$

where DW is the dry weight of the phytoplankton in milligrams, and V is the volume in mm^3. According to this equation 0.263 mgs. of the dry weight represents the mean quantity of detritus and animals, and the mean weight of phytoplankton is 0.336 or 39% of the volume of phytoplankton.

The organic matter in the phytoplankton can be determined in the same way. The equation is

$$OM = .277\,V + .146 \qquad (2)$$

where OM is the weight of organic matter in the phytoplankton in milligrams, and V is the volume of phytoplankton. The mean weight of organic matter in the phytoplankton is found to be 0.237, or 28% of the volume.

According to the first equation the average phytoplankton constituted 56% of the sample, as compared with 62% in the second equation. The results can be checked in still another way. There is a time in the early spring when the quantity of zooplankton is still small and when the phytoplankton is growing so actively that there is relatively little planktogenic detritus. At that time the sample should be composed almost entirely of phytoplankton. At the four stations on the March cruise where there was a pronounced growth of diatoms—3798, 3813, 3817, and 3824—the ratio of organic matter to volume varied from 10 to 47% with a mean value of 26%, which checks fairly closely with the mean of 28% derived from equation (2). Thus, while the individual values may vary considerably, it appears that the treatment has been accurate enough as far as the averages are concerned.

In quantitative work it is extremely useful to have a set of conversion factors by which one type of plankton measurement can be converted into another. Thus far two of them have been derived. The dry weight appears to be about 40 per cent of the volume, and the organic matter about 25%. The wet weight cannot be determined, except very roughly by assuming that the specific gravity of the

plankton is unity, in which case the wet weight would equal the volume. This assumption seems unwarranted, however.

Since most of the subsequent measurements are in terms of plant pigments, which are stated in completely arbitrary units, it is convenient to derive the other values in relation to pigment content. The regression equation used is

$$V = .141\ PP - .012 \qquad (3)$$

where V is the volume of phytoplankton in mm^3, and PP is the number of Harvey units of plant pigments. The residual value is insignificantly small indicating that all the plant pigments were contained in the phytoplankton. There is little difference between the equation and the ratio between the means of the two measurements, which may be expressed as $V = 0.139\ PP$. Then the dry weight would be about $0.055\ PP$, and the organic matter $0.035\ PP$. The normal carbon content of phytoplankton is slightly less than half the weight of organic matter, or $0.017\ PP$.

The Distribution of Plant Pigments

During the cruise of September, 1939, the plant pigments at the surface ranged from 1600 to 17,900 Harvey units per m^3, with a mean value of 7760 units. At a depth of ten meters the average concentration was slightly higher, 8240 units, and at thirty meters it was 7950. Below thirty meters the quantity generally diminished rapidly but was readily measurable even at a depth of 200 m. at the three deep-water stations. The mean vertical distribution is shown graphically in Figure 1.

Although the average quantity was greatest at ten meters, the depth of the maximum concentration varied considerably from station to station. Six of the twenty-six analyses showed the largest quantity to be at the surface, and of these four were in relatively shallow water with a depth of less than 75 m. At eight stations, of which five were in shallow water, the maximum was at 10 m. The maximum occurred at 30 m. at ten stations, of which only two were in shallow water, and at 50 m. at two deep water stations. With more complete sampling of the vertical column the point of the maximum occurrence of phytoplankton might be shifted upward or downward a few meters at each station. It is evident, however, from the avail-

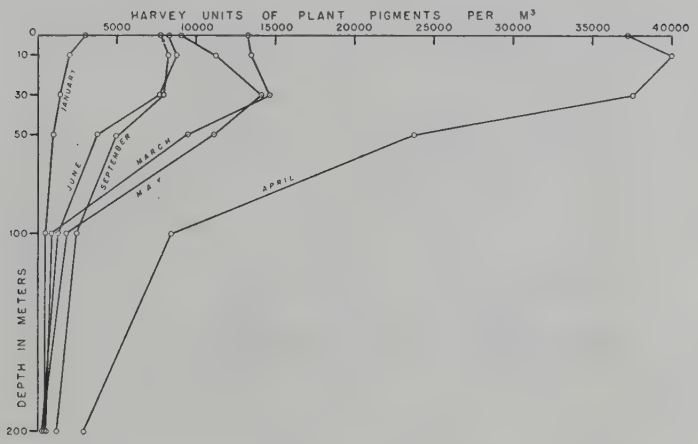

Figure 1. The mean vertical distribution of plant pigments on Georges Bank.

able figures that this point varied considerably and that it was related to the depth of the vertical column, being near the surface in the shallow part of the bank and lower in the deeper water.

Figure 2 shows that in September the largest quantities of plant pigments in the surface water occurred in the northern part of Georges Bank, not only in the very shallow central region, but also extending northeast and southwest as a broad strip running parallel to the long axis of the bank. To the northward and southward there was a fairly uniform decrease, with the smallest quantities occurring in the deep water south of the bank.

The concentration in the surface water and at depths of 10 and 30 m. was closely related to the depth of the water column. Within the 30-fathom curve the mean surface phytoplankton measured 11,700 Harvey units per m^3. Between the 30- and 50-fathom curves it was 4380 units, and outside the 100-fathom contour the average was 2330. But although the quantity of plant pigments per unit volume was much greater in shallow water, the phytoplankton in the deep water extended through a longer vertical column, so that the total quantity underlying a unit area of sea surface did not show such pronounced variation. Within the 30-fathom curve there was an average total crop of 572,000 Harvey units per m^2. Between 30 and 50 fathoms

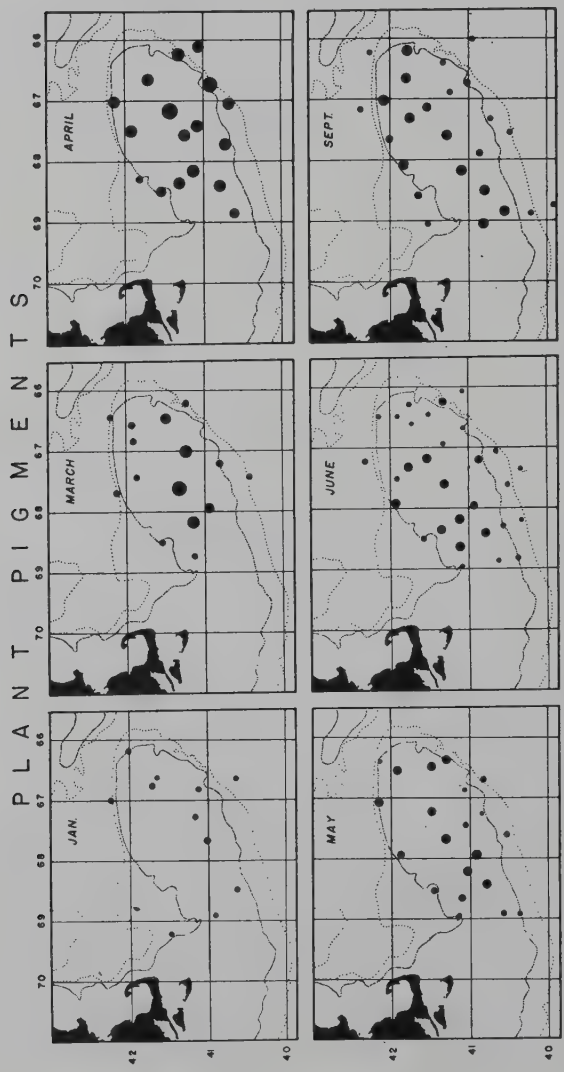

Figure 2. The horizontal distribution of plant pigments in the surface waters. The size of the dots is graduated to indicate the relative abundance of phytoplankton. Exact values are listed in Table VII.

it was 552,000; between 50 and 100 it was 589,000; and outside the 100-fathom curve it was 537,000. None of these differences can be regarded as significant.

At the time of the January, 1940, cruise the surface phytoplankton had become reduced to about 40% of the September value, and the total crop to 20%. The averages by depth were as follows: surface, 3000 Harvey units per m^3; 10 m., 2030 units; 30 m., 1410; 50 m., 960; 100 m., 470; 200 m., 400 units. In January the maximum quantity occurred at the surface at all except one station, which had equal amounts at the surface and at 10 m. The variations from one station to another were small and irregular. Neither the surface concentration nor the total crop showed gradients from shallow to deep water, and the total range of variation in the surface water was from 1700 to 6400 units per m^3, or about one-third of the September variation.

At the time the third cruise was made to Georges Bank, near the end of March, 1940, the spring diatom burst was beginning. Pronounced growth had taken place near the center of the bank. In the deeper water to the northward and southward the increase was slight but significant. As in September, the relationship between the concentration of phytoplankton and the depth of water was marked. Where the water was less than 30 fathoms the average quantity of plant pigments was 30,400 units per m^3. Between the 30- and 50-fathom curves the average was 11,500 units; between 50 and 100 it was 4400, and beyond 100 fathoms it was 6070 units. Also, for the first time, a similar gradient appeared in the total quantity of plankton per unit area. In water of more than 50 fathoms' depth there was an average crop of about 350,000 units per m^2, which was less than in September but between two and three times the January crop. In the shallow water of less than 30 fathoms it was 1,532,000 units per m^2, and between 30 and 50 it was 867,000, roughly ten times as much as in January.

In all the analyses of surface water the plankton varied from 2100 to 56,000 units per m^3, with a mean value of 13,260 units. The averages for the other depths were as follows: 10 m., 13,490; 30 m., 14,670; 50 m., 9470; 100 m., 830; and 200 m., 500. At each depth there had been an increase since the January cruise. Down to 50 m. there was more plankton than there had been in September; at 100 and 200 m. there was less. At four stations in deep water the maximum concentration lay at the surface, and at two stations the surface

and 10 m. analyses were identical. Two others had maxima at 30 or 50 m. The shallow water stations had a general distribution, with the largest quantity at the surface at one station, and two each with maxima at 10, 30, and 50 m.

By the middle of April the spring diatom burst had reached large proportions at every station on the bank and in much of the surrounding water as well. The plant pigments during the April cruise varied from 4200 to 65,000 units, with only two analyses, both at the northwestern edge of the bank, of less than 20,000. The averages at various depths were as follows: surface, 37,200; 10 m., 40,070; 30 m., 37,530; 50 m., 23,770; 100 m., 8470; and 200 m., 2900. Thus between the end of March and the middle of April there had been an increase of two to ten-fold at every depth, and the total crop had nearly tripled itself during the two weeks interval. Most of this increase had occurred in the deep-water areas; the shallow stations apparently had come nearly to their peak by the end of March, and they increased only about one and a half times between the March and April analyses. The mean values for surface plankton according to the depth of water were as follows: less than 30 fathoms, 44,600 units of plant pigments per m^3; 30 to 50 fathoms, 36,800; 50 to 100, 30,950; greater than 100 fathoms, 23,050 units. Thus the gradient in concentration between shallow and deep water, while still readily observable, had decreased greatly. Moreover, coincident with the development of the spring diatom burst in deep water, the gradient in the total quantity of plankton per unit area had disappeared. The mean crop in all the analyses was 2,303,000 units per m^2, and the variation with depth was from 2,053,000 to 2,535,000, with the largest quantity occurring between the 30- and 50-fathom curves.

In deep water the largest concentration occurred at the surface or at 10 m. In shallow water the maximum was again observable anywhere from the surface to 50 m., but in the majority of stations it was in the upper 10 m.

The May cruise was begun about two weeks after the last April analysis. During that time the spring diatom burst had largely disappeared. The plant pigments at the surface averaged 9050 Harvey units per m^3, approximately one-fourth of the April value. At 10 m. the mean was 11,260 units; at 30 m. it was 14,150; at 50 m., 11,150; at 100 m., 1800; and at 200 m., 300 units. Thus at various depths the decrease ranged from 60% to 90%. It was greatest at 200 m. and

least at 30 m. For the first time the mean concentration of plant pigments was greatest at 30 m. In shallow water the maximum concentration occurred at 30 m. at six stations. It was at 10 m. at three stations and at 50 m. at two stations. On no occasion did it occur at the surface. In the deeper water the position of the phytoplankton maximum lay anywhere from the surface to 50 m. but occurred most frequently at 10 m.

The vertical distribution tended to be very irregular. It was not unusual to find a particular stratum ten or twenty times as rich in phytoplankton as the water immediately above or below it. Generally in such cases the quantity of plankton was very small at the surface and at ten meters, with a sudden increase at 30 m.

The horizontal gradients in concentration increased slightly, for the diminution in the quantity of plankton had been less in the shallow than in the deeper water. Within the 30-fathom curve the plant pigments averaged 19,900 units per m^3 at the surface. Outside this region the average quantity decreased regularly from 6780 to 4000 units. There was also some evidence of the reestablishment of a gradient in the total quantity of plankton. The horizontal distribution resembled that of the September cruise, with the largest quantities occurring in a strip running lengthwise of the bank slightly north of its center.

A month later conditions had not changed radically. The average quantity of phytoplankton at the surface was only slightly less. Its horizontal distribution had changed in that the northeastern stations had suffered considerable decreases. Thus the zone of high concentration was compressed into the central and western part of the bank. The horizontal gradients, both as to surface plankton and the total crop, were about the same.

The mean vertical distribution during the June cruise was as follows: surface, 8300 units; 10 m., 8800; 30 m., 7760; 50 m., 3730; 100 m., 1280; and 200 m., 300 units. It is evident that the concentration in the middle depths had decreased considerably; the vertical distribution was much like that of the previous September. The violent irregularities in the vertical distribution at individual stations had largely disappeared. In the deep water the depth of the zone of the maximum occurrence of phytoplankton was approximately the same as it had been in May. In the shallow water it had risen considerably.

With only six cruises to Georges Bank, covering only one year's

time and with large gaps in the summer and autumn seasons, it is impossible to know how closely the present data correspond to average conditions on Georges Bank. But regarding the data as valid at present only for the period of the examination, they may be summarized as follows:

During parts of two summer periods (September, May, and June) the phytoplankton occurred in moderately large concentrations in the upper thirty or fifty meters of the north central part of the bank. The zone of high concentration generally extended northeast and southwest of the central portion, parallel to the long axis of the bank and slightly north of its center. The concentration decreased gradually toward the deeper water on all sides. In spite of the high concentration in shallow water, the total quantity of plankton underlying a unit area of surface was not markedly greater than in the deep water, for in the latter plankton occupied a longer vertical column, occurring in considerable quantities to a depth of at least two hundred meters. During January the quantity of plankton was small, averaging less than at any other time when analyses were made. It was largely concentrated in the surface layers and was not more abundant in the shallow water of the bank than in the surrounding deeper water. The spring diatom burst probably began in March and ended in May. It started in shallow water near the center of the bank and reached large proportions there before the burst started in the deeper water. It also lasted longer in the shallow water, but at the height of the bloom the concentration was only slightly greater than in the surrounding oceanic waters. The only times during the year when the total standing crop on the bank was observed to be greater than in the deep water were at the beginning and end of the spring diatom burst. Following the spring bloom the vertical distribution of plankton was very irregular, frequently with very small concentrations at the surface and very large ones at depths of 30 or 50 m. The largest observed concentration of plankton during the spring bloom was about one hundred times the smallest concentration found in the surface water immediately afterward, and the difference between the largest total crop and the smallest one, the latter occurring in January, was of the same order of magnitude.

The Distribution of Nitrate and Phosphate

The mean vertical distribution of nitrate and phosphate during the six cruises to Georges Bank is shown in Table IV, and the horizontal distribution of phosphate in Figure 3.

During the time of the September cruise the mean phosphates and nitrates were lowest at the surface and increased regularly with depth. The total range of surface phosphate was 0.03 to 1.04 mg.-atoms of P per m^3, and that of nitrate was 0.7 to 9.7 mg.-atoms of N. It is

TABLE IV

VERTICAL DISTRIBUTION OF NITRATE AND PHOSPHATE

(mg.-atoms of N or P per m^3)

	Depth	1	10	30	50	100	200
Phosphate	*Sept.*	0.373	0.402	0.645	0.933	1.431	2.077
	Jan.	1.099	1.092	1.175	1.180	1.183	1.740
	Mar.	1.123	1.152	1.165	1.318	1.415	1.705
	Apr.	0.847	0.675	0.734	0.930	1.180	1.750
	May	0.690	0.470	0.606	0.827	1.105	1.400
	June	0.670	0.590	0.729	0.961	1.122	1.775
Nitrate	*Sept.*	4.25	5.05	5.77	6.21	8.17	11.47
	Jan.	8.10	6.80	6.65	8.69	10.00	16.95
	Mar.	5.98	5.57	5.85	6.08	7.25	16.45
	Apr.	3.72	4.16	4.74	8.68	11.83	16.10
	May	7 53	9.18	10.90	9.75	16.15	15.50
	June	5.07	4.90	5.38	7.64	13.13	17.80

worthy of note that no sample, either at the surface or elsewhere, showed complete exhaustion of N or P. The largest concentrations of surface nutrients were found in shallow water. Within the 30-fathom curve the mean surface phosphate was 0.63 mg.-atoms per m^3, and the nitrate was 6.4. Between the 30- and 50-fathom contours the phosphate was 0.43; between 50 and 100 it was 0.15, and beyond 100 fathoms it was 0.16 mg.-atom. Outside the 30-fathom curve the nitrate showed no further gradations, the averages lying between 3.4 and 4.4 mg.-atoms per m^3.

In January the phosphates showed a considerable increase over the September values in the upper fifty meters, and the averages for the 100 m. and 200 m. depths had decreased slightly. The mean quantity

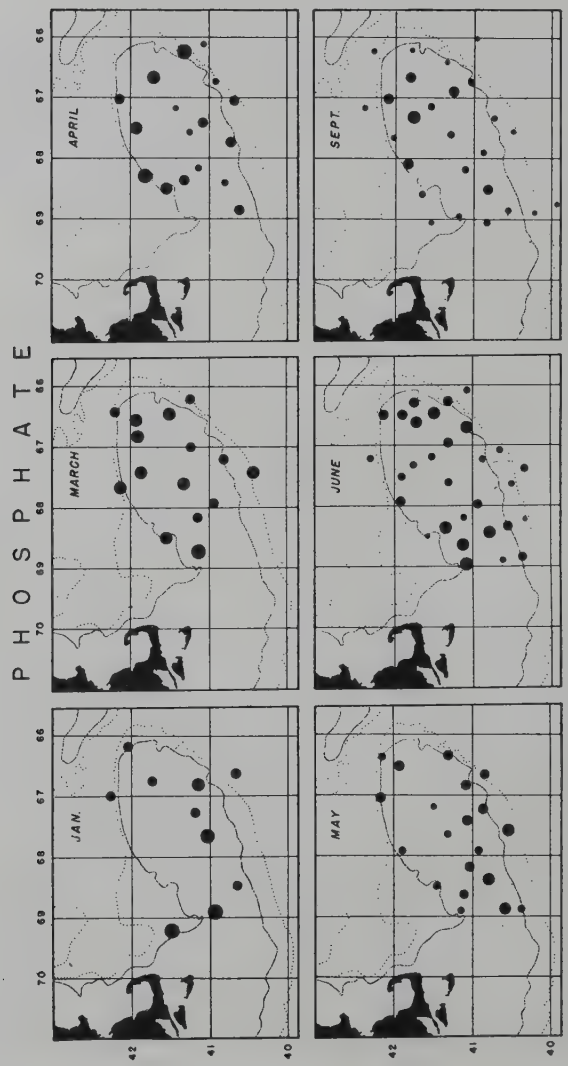

Figure 3. The horizontal distribution of phosphate in the surface waters.

of phosphate was very nearly the same throughout the first hundred meters, showing only a slight reduction at the surface. Nitrate had increased at all levels. It was not, however, distributed uniformly in respect to depth. Lower values were obtained at the 10 and 30 m. levels than at the surface and 50 m. Below 50 m. there was a marked vertical gradient in the nitrate concentration.

Between September and January the mean total quantity of phosphate underlying a unit area of surface increased from 62.1 to 88.8 mg.-atoms of P per m^2, and the nitrate increased from 446.7 to 706.5 mg.-atoms of N. But although the averages showed a definite trend, the values at individual stations varied considerably. Nor was there any uniformity in horizontal distribution, and the variations in nitrate and phosphate showed no evidence of the gradients between shallow and deep water observed during the September cruise.

In March a further slight increase in phosphate had taken place. The mean total quantity was 93.7 mg.-atoms of P per m^2, about five per cent higher than in January. The mean vertical column showed a slight gradient from the surface to 30 m. and a more pronounced one from 30 to 200 m. The surface phosphate was slightly lower in the shallow water than elsewhere.

A more pronounced change occurred in nitrate. The mean total nitrate had decreased from the January value of 706.5 mg.-atoms per m^2 to 527.6 mg.-atoms, a reduction of twenty-five per cent. The decrease in the upper thirty meters was about eighteen per cent. The averages for the vertical column show that in March the quantity of nitrate was nearly uniform throughout the upper fifty meters. It was less at 10 and 30 m. than at the surface and 50 m., but the difference was very slight. Below 50 m. there was a strong vertical gradient. The nitrate, like the phosphate, was slightly lower in the shallow water within the 30-fathom curve.

In April the mean total phosphate was 21.9 mg.-atoms of P per m^2 in the upper 30 m. This was 37% less than in March and 35% less than in January. The quantity in the entire mean vertical column was 61.8 mg.-atoms, which was also a decrease, 34% less than in March, 30% less than in January. Reduction had occurred at all depths except 200 m. but was most marked at 10 and 30 m. The largest decrease in surface phosphate had occurred within the 30-fathom contour where the mean value was 0.69 mg.-atom per m^3, or 67% of the March observations. Between the 30- and 50-fathom

curves the average was 0.82 mg.-atom, which was 69% of the March values. Beyond 50 fathoms there was no significant decrease.

Between the March and April cruises the nitrate also changed considerably. The mean value for nitrate in the upper thirty meters in April was 128.7 mg.-atoms per m^2, a decrease of 25% since March and 39% since January. The total quantity of nitrate was 483.6 mg.-atoms, a decrease of 8% between the March and April cruises and a total decrease of 32% since January. Unlike phosphate, the greatest nitrate reduction occurred at the surface; the decrease there was 39% as compared with 25% at 10 m. and 19% at 30 m. At 50 and 100 m. there was an increase in nitrate, and the 200 m. depth remained about the same. Within the 30-fathom contour the mean surface nitrate was 2.5 mg.-atoms per m^3. This was the lowest average obtained thus far, but in no case did the nitrate approach the point of exhaustion, nor was the smallest value observed, 2.1 mg.-atoms, as low as some of the September measurements. The areas outside the 30-fathom curve all had higher nitrates than the very shallow water, but they had undergone considerable decreases since the March cruise. No further indication of a gradient in concentration was observed between the 30-fathom limit and deep water.

In May the phosphate had undergone further decrease at all depths. The minimum value was still at 10 m., and the 30 m. average was still lower than the surface or 50 m. The decrease was 24% in the upper 30 m. and 35% in the entire water column. The surface phosphate was lower in the shallow than in the deeper water, but the gradient was not as marked as it had been during the previous cruise.

The nitrate changed in the opposite direction between the two cruises. The average in the upper 30 m. was 284.5 mg.-atoms of N per m^2 or 2.2 times the April average, and the total quantity was 608.0 mg.-atoms, an increase to 1.25 times the previous value. The increase was apparent at all depths except 200 m. but was most marked in the upper 30 m. There the ratios of the April to the May values were as follows: surface, 1 : 2.02; 10 m., 1 : 2.21; 30 m., 1 : 2.30. In the upper 30 m. the nitrate was 36% higher than it had been in January, and in the total column it was 14% lower. The increase was relatively greatest in shallow water, so that not only was the gradient observed during the previous two cruises destroyed, but there was a slight tendency toward the establishment of one in the opposite direction, with the largest quantity of nitrate in the shallow water.

By the next month this opposite gradient was more marked, with a mean surface nitrate of 6.2 mg.-atoms per m^3 within the 30-fathom contour and values outside in the deeper water ranging from 4.6 to 5.2 mg.-atoms. Thus the horizontal distribution of surface nitrate during the June cruise was essentially the same as it had been the previous September.

The quantity of nitrate in the upper 30 m. decreased 46% between the May and June cruises, returning nearly to the April level. The total nitrate decreased 25%. The reduction occurred at all levels except the 200 m. depth and was most marked at 30 m., where during the previous period the increase had been greatest. The lowest mean value for nitrate was at 10 m.; the surface and 30 m. were slightly higher, and the quantity increased rapidly below 30 m.

The phosphate was higher in June at all levels except the surface, where a very small decrease occurred. The mean quantity in the upper 30 m. was 19.2 mg.-atoms per m^2, an increase of 16%. The total for the whole vertical column averaged 53.2 mg.-atoms, a 33% increase.

The surface phosphate had increased slightly in shallow water, from 0.52 to 0.55 mg.-atoms per m^3 inside the 30-fathom contour, and from 0.73 to 0.84 mg.-atom in the water of 30 to 50 fathoms. Between 50 and 100 the phosphate decreased from 0.73 to 0.49, and beyond the 100-fathom curve it changed from 0.77 to 0.36. Thus the largest quantity occurred not in the shallow water as it did the previous September, nor in the deep water as in the spring months, but in water of intermediate depth.

Percent Saturation of Oxygen

The variations in the mean percent saturation of oxygen with depth are shown in Table V.

TABLE V

Percent Saturation of Oxygen

Depth	*Sept.*	*Jan.*	*Mar.*	*April*	*May*	*June*
1	102.0	94.3	101.3	112.9	110.2	105.0
10	102.2	94.3	101.5	111.6	110.6	105.0
30	98.8	94.3	100.7	108.3	106.9	100.9
50	91.5	91.9	98.0	101.6	100.9	95.2
100	80.1	80.7	90.3	87.3	86.5	85.8
200	61.3	65.0	67.0	77.0	——	81.0

During the September cruise the upper ten meters were slightly supersaturated, while below this point the concentration dropped off rapidly. At a few stations the thirty-meter water was also supersaturated, and at four of them the maximum percentage of oxygen was found at this depth. Whenever this occurred it was accompanied by a concentration of phytoplankton.

Variations in the horizontal distribution of oxygen were not very great but were probably significant. The largest supersaturation of oxygen in the surface water occurred between the 30- and 50-fathom contours, and the smallest in the shallow water within the 30-fathom curve. Intermediate values were observed in the surrounding deeper water. The total quantity of oxygen in excess of saturation averaged 6.00 g. per m^2. The largest excesses were found in deep water.

In January the upper 30 m. were uniformly under-saturated. Below 30 m. there were further decreases in the percent saturation. The values for these lower depths were nearly the same as in September. No significant horizontal variation was found.

Between January and March significant gains in oxygen were made at all depths. The mean values for the upper 30 m. showed slight supersaturation. The greatest gains had been made in the water within the 30-fathom line, where the water was 106% saturated, and the total oxygen in excess of saturation was 16.9 g. per m^2. Between 30 and 50 fathoms the surface was 101%, and the excess oxygen measured 10.8 g. Beyond 50 fathoms the water was under-saturated.

April again showed gains in oxygen at all levels, and the water was supersaturated to a depth of at least 50 m. The surface water had a mean value of 112.9%, and the total oxygen in excess of saturation averaged 40.94 g. per m^2. The horizontal variation was similar to that of the previous month but at a higher level, with the averages ranging from 107% in the deepest water to 115% in the shallowest. The variation in total oxygen was from 15.0 to 47.9 g. in excess of saturation.

The oxygen during the May cruise was reduced slightly from the high April values. The mean total oxygen declined 10%, and the saturation value at the surface declined 2.7%, with smaller decreases at lower levels. The horizontal distribution of surface oxygen remained much the same, with values ranging from 105% in the deep water to 112% inside the 30-fathom contour. The total oxygen, how-

ever, was spotty, and the gradient, although recognizable, was not marked.

Between the May and June cruises sharper oxygen losses occurred, amounting to five or six percent in the upper fifty meters. The lower level of supersaturation moved up from 50 to 30 m. The total oxygen in excess of saturation averaged 12.13 g. per m^2, or 33% of the May value. The horizontal distribution of surface oxygen percentages was as follows: less than 30 fathoms depth, 104%; 30 to 50 fathoms, 105%; 50 to 100, 107%; in depths greater than 100 fathoms, 99%. Thus the horizontal variations were beginning to resemble the conditions observed during the previous September, when the largest concentrations were found in water of intermediate depth. The distribution of total oxygen was similar. The largest value, 15.5 g. per m^2 in excess of saturation, occurred between 50 and 100 fathoms; the smallest average, 4.8 g., was obtained in deep water, and the shallow depths had intermediate values.

Oxygen Production and Consumption

The horizontal distribution of the experimental values for surface oxygen production are shown in Figure 4. The mean surface oxygen production during the September cruise was 0.149 g. per m^3 per day. The average production in the waters within the 30-fathom contour was 0.27 g.; between 30 and 50 fathoms it was 0.13 g.; between 50 and 100 it was 0.15 g.; and beyond 100 fathoms it was 0.04 g. Thus it is apparent that oxygen production, as well as plant pigments and other biological substances, showed a distinct gradient between shallow and deep water.

The total range of individual analyses was — 0.22 to 0.49 g. per m^3 per day. Negative values, although theoretically impossible according to the plan of the experiments, occurred occasionally in all the cruises. A small negative value is of doubtful significance since it may arise from errors of sampling or analysis. A large one, such as the one just quoted, is almost certainly real, and is due to greater oxygen consumption in the light bottle than in the dark. There is some evidence that this occurs particularly when the quantity of animals is large (cf. Riley, 1941). It follows logically that there is some error in all the experiments and that the recorded result is a minimal estimate of photosynthetic activity. The magnitude of

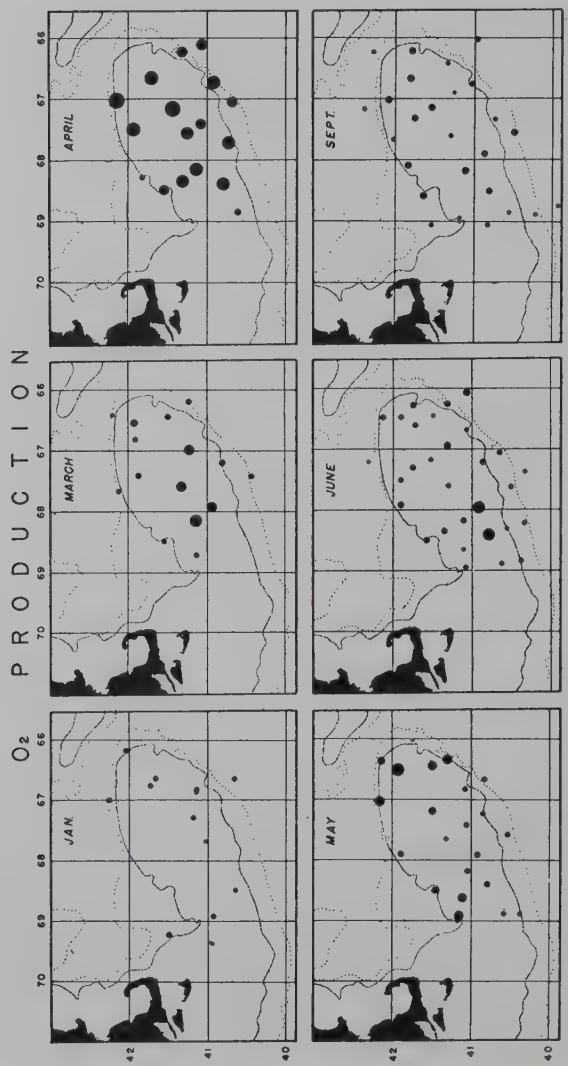

Figure 4. The horizontal distribution of the experimental values for oxygen production in the surface water.

the error is difficult to determine in the marine environment. In freshwater associations it may be as much as 40% (Riley, 1939).

During the January cruise the mean oxygen production was 0.036 g. per m^3 per day, with a total range of — 0.04 to 0.10 g. There was no evidence of consistency in the horizontal distribution.

In March, coincident with the beginning of the spring diatom burst in shallow water, the oxygen production increased. The averages were as follows: within the 30-fathom curve 0.74 g. per day; from 30 to 50 fathoms, 0.29 g.; 50 to 100, 0.05 g.; outside the 100-fathom line, 0.09 g. The average of all stations was 0.307 g. per m^3 per day, and the total variation at individual stations was — 0.03 to 1.34 g.

Further increases were noted in April. The production ranged from 0.06 to 2.35 g., with an average of 1.054. The gradient in production was marked. It averaged 1.45 g. in the shallow water; between 30 and 50 fathoms it was 1.01 g.; between 50 and 100 it was 0.70; and beyond 100 fathoms it was 0.37 g.

By the time of the May cruise a considerable decrease in oxygen production had occurred. The horizontal distribution was irregular, but there was a slight tendency toward a reversal of the previous trend, with the maximum production in the area between the 50 and 100-fathom curves. The averages were as follows: less than 30 fathoms, 0.26 g. per m^3 per day; 30 to 50, 0.31 g.; 50 to 100, 0.43; and in greater depths than 100 fathoms, 0.10 g. The average of all the analyses was 0.324 g., with a total range of — 0.09 to 1.71 g.

A further slight decrease occurred between the May and June cruises. In June the mean production was 0.240 g., with a variation of — 0.18 to 1.16 g. Slightly higher values were obtained in shallow water than at the deep stations.

There is little evidence available on the vertical distribution of photosynthetic activity. Only one experiment was completed successfully, and the bottles were exposed only from noon until sunset, so that the experiment was useless for determining the compensation point. The experiment was made at Station 3946 on the June cruise. The Secchi disc reading was 11 m.; the bottles were filled with water from the depth at which they were to be exposed. The following results were obtained: 1 m., 0.10 g.; 5 m., 0.03; 10 m., 0.42; 20 m., 0.11; 30 m., 0.10; and at 40 m., — 0.03 g.

The mean values for oxygen consumption obtained during the six cruises were as follows: September, 0.221 g. per m^3 per day; January,

0.006; March, 0.137; April, 0.288; May, 0.175; and June, 0.284 g. During the September and June cruises the average values for oxygen consumption were higher than those for production. It seems likely that such would not be the case in the natural environment since the surface waters during these cruises were slightly supersaturated with oxygen. There are probably two errors involved. The first one was mentioned above, namely, that the values for oxygen production are minimal. The second error is due to the well known fact that bacteria multiply more rapidly in enclosed spaces than in the free water. Thus the ratios between production and consumption are far from dependable, although the general seasonal trend is probably valid.

The oxygen consumption during January was smaller than at any other time of the year. The mean value was of about the same order of magnitude as the analytical error, so that the results are not trustworthy. The largest average oxygen consumption occurred in April, and was apparently due to the respiration of the large quantity of phytoplankton in the water at that time.

The horizontal distribution of oxygen consumption was quite different from that of production. In five of the six cruises the largest surface oxygen consumption was observed to be somewhere in the middle depths, between 30 and 100 fathoms. The deep water generally had the lowest surface values, and the shallow water was slightly higher. Only during the March cruise were the largest values for consumption found within the 30-fathom contour.

DISCUSSION

Nutrients

The dissolved nutrients in the Georges Bank area showed certain general characteristics. In the first place, the ratio of nitrate to phosphate was relatively low. For oceanic waters in general, Cooper (1938) has suggested an average ratio of 15 : 1. On Georges Bank the average in the surface waters varied from 4 : 1 in April to 11 : 1 in September. It has been suggested (Riley, 1941) that a low N : P ratio is characteristic of shallow regions because the rapid return to the surface waters of nutrients regenerated on the bottom leads to a preponderance of the more quickly regenerated phosphate. This theory finds support in the fact that on Georges Bank the ratio was

highest during the September cruise when the vertical stability was greatest, and it was least in March and April when the waters were mixing freely. Moreover, in September there was a decrease in the N : P ratio below the zone of growth, suggesting not only that the rate of regeneration was different from the rate of utilization, but also that more rapid vertical transport would lower the ratio in the surface waters.

This situation did not occur during the spring months. On the contrary, the N : P ratio tended to be lower in the upper waters. But whether this was due to more rapid utilization of nitrate by phytoplankton or to regeneration of phosphate in the surface water cannot at present be decided with any certainty.

Further analysis of the nutrients on Georges Bank is concerned with a study of individual processes, such as regeneration, vertical transport, consumption by green plants, and horizontal water movements, and the attempt to synthesize the observations into a consistent whole.

The evidence, largely of an indirect sort, indicates that on Georges Bank regeneration occurs throughout the vertical water column and on the bottom mud. During the September cruise nitrate production and consumption experiments were conducted on the surface water at all stations. The mean consumption of nitrate in the experimental bottles was found to be 1.06 mg.-atoms of N per m^3 per day, and the regeneration was 3.19 mg.-atoms. The results are probably somewhat in error; it is unlikely that production was actually so much greater than consumption. It is more reasonable to suppose that it was caused by the abnormal amount of bacterial activity occurring in the dark bottle. Nevertheless, the fact that it occurred at all would indicate that the bacteria concerned in the process are present in oceanic surface waters and presumably carry on their functions to some extent in the natural environment, although it is impossible to determine from the experiments how much of the total regeneration could be accounted for in this way.

The occurrence of regeneration at the surface is indicative of the same sort of phenomenon in deeper waters. Probably it is somewhat greater there, since presumably the bacterial substrate is more abundant.

Most investigators believe, however, that the greater part of the regeneration occurs at the bottom. Rakestraw (1933) analyzed bot-

tom water brought up with a grab on Georges Bank and found that it contained 350 mg. of nitrate and 25 mg. of nitrite per m^3, as compared with 75 mg. of nitrate and 3.9 of nitrite in the water four meters above. This accumulation of nutrients in the water at the surface of the mud is presumably due to the decay of organisms falling to the bottom, of which there is apparently a liberal supply throughout the year. During the spring months it was not uncommon in the shallow water to find more plankton near the bottom than anywhere else, and in no case was there evidence that the crop was completely consumed before it reached the bottom. Thus, with living plankton falling to the mud, as well as the usual rain of fecal pellets and other organic particles, there is reason to believe that the mud-water interface was a potent source of dissolved nutrients.

Closely connected with regeneration is the phenomenon of vertical transport. In September, in depths of about sixty meters or less on Georges Bank the temperatures were approximately uniform from surface to bottom. During the winter and spring months mixing probably occurred to a depth of one hundred meters or more. In such areas vertical transport would be fairly rapid, and the amount of nutrients supplied to the surface water would be limited more by the rate of regeneration than by the rate of vertical turbulence. In water of greater depth, where the supply of nutrients is always super-abundant below the phototrophic zone, the quantity of nutrients at the surface would be entirely dependent on the rate of vertical transport. The latter of course occurs to some extent throughout the year but is most pronounced during the winter season. The rate of regeneration, on the other hand, is highest in the summer. Since the light intensity is more favorable for plankton growth in the spring and summer, it follows that the period of potential plankton growth coincides with the period when there is an adequate supply of nutrients much more closely on a shallow bank than in deeper water. Thus a larger concentration of plankton is maintained in the surface water throughout most of the year than is possible in deep water. This is at least partly offset, however, by the self-limiting effect of plankton, in which, by growing in the surface water in high concentration, the plankton and the detritus derived from it reduce the transparency of the water, thus reducing the thickness of the phototrophic zone. The net result of these interacting phenomena on Georges Bank appears to be a higher concentration of both plankton and nutrients in the

shallow water (together with a lower transparency), but an approximately uniform total crop regardless of depth and a total supply of nutrients in the part of the water column in which the plankton occurs that is even greater in deep water than in the shallow part of the bank.

The last point requires further explanation. In the deep water surrounding the bank living plankton was found at all depths down to at least two hundred meters. Experimental evidence (Harvey, 1933; Ketchum, 1939; Riley, 1941) shows that there is nothing to prevent plankton from utilizing nutrients and growing in the waters below the phototrophic zone provided it had been there recently enough to have a store of reserve food to supply energy for the process. However, growth could not continue very long unless the plankton were carried back to the phototrophic zone. In the second place, when the nutrients and plankton are spread thinly through a long vertical column, the utilization of nutrients is not as efficient (according to the mass action law which can be applied here) as when they are both concentrated in a small volume. Both these considerations lead to the conclusion that to grow a given quantity of plankton in a small volume of water does not require as large a total quantity of nutrients as to grow it in a larger volume of water in the same length of time.

It is impossible at present to make a satisfactory analysis of the effects of horizontal water movements on the nutrients of Georges Bank. It has been noted above that the currents tend to run in clockwise eddies around the bank, especially during the summer months. It is therefore presumably a common occurrence for the bank water to stay there a month or several months during the course of its clockwise migration and to be relatively isolated during that time from surrounding bodies of water. The quantity of nutrients and their changes in concentration during such a time might be expected to depend on the normal seasonal trend of physical and biological events. This was true during the September cruise (C. O'D. Iselin, private communication), so that it was considered valid in the previous paragraphs to discuss the summer conditions on the bank as if it were in a static condition.

There is some evidence, however, that during part of the investigation there were movements of water across the bank. There were changes in salinity between successive cruises which were most marked near the edge of the bank and decreased in shallow water, which in-

dicated some interchange, although temperature-salinity correlations were inadequate to explain exactly what happened. Moreover, there were changes in nutrients which seemed to indicate horizontal water movements. The large increase in nitrate during May should be questioned in this respect, for there were no biological events on the bank that seemed to warrant it. The spring diatom burst was disappearing rapidly, but the regeneration of nitrogen does not ordinarily follow so quickly upon the heels of a bloom. Furthermore, quantitative analysis of the data shows no evidence of a relationship between surface nitrate and plant pigments during either May or April, although the correlations were highly significant in January and March. It seems advisable, therefore, to examine the data for non-biological factors. For this purpose twelve stations were chosen which were visited on both the April and the May cruises. At these stations the change in surface nitrate varied from 8.0 to — 4.5 mg.-atoms of N per m^3, with a mean change of 3.2 mg.-atoms. The changes in salinity varied from 0.24 to — 0.36‰, with a mean change of — 0.10‰. The correlation between changes in nitrate and salinity was — .350. Further analysis reveals that between the March and April cruises there was an increase in salinity corresponding with a decrease in nitrate, with a correlation of — .615. Similar correlations for the period from January to March and from May to June are negligibly low. Such relationships lack the degree of absoluteness required in the analysis of current systems by means of T-S correlations, but they lend support to the hypothesis that the nitrate variations during April and May were biologically anomalous.

The phosphate data lend no aid in solving the problem. They showed no relation with salinity during any of the cruises. Their correlation with plant pigment were not as high during January and March as the plant pigment-nitrate relationship, nor as low as were the latter during April and May. This is hardly contradictory to the above theory; the difference in the behavior of phosphate provides a relatively simple explanation of the phenomenon. It has been pointed out that the ratio of N to P on the bank was low. It follows that phosphate would suffer less complete reduction than nitrate during the spring diatom burst. Moreover, that which was used would be regenerated more quickly. Both these factors would tend to diminish the correlation between plant pigments and phosphate, and at the same time to insure that there would be no great difference

between the phosphate concentration of the bank water and that of the deeper water off the bank, from which any replacement must be derived and which presumably would have suffered little diminution of either nutrient.

The nutrients on Georges Bank may be summarized as follows: There was a low N : P ratio, which appears to be characteristic of shallow water. During May, June, and September the concentration of nutrients in shallow water was relatively high. This was probably due to the rapid rate of regeneration; there seems to have been little upwelling of deep water during the summer period. In the spring months, when the temperature was too low for rapid regeneration and when the concentration of plankton on the bank was greater than in the surrounding water, a reverse gradient developed, with the smallest concentration of nutrients in shallow water. Some of the changes in nutrients that occurred during the spring months are believed to be due to horizontal water movements. The quantitative relations of nutrients and phytoplankton will be analyzed in subsequent sections.

Phytoplankton

The Relation of Plant Pigments to Environmental Factors

In order to determine the relationships of the phytoplankton with environmental factors of the Georges Bank area, correlations of plant pigments with temperature, nitrate, and phosphate were calculated for the surface water and for the entire vertical column.

During the September, May, and June cruises there was a significant negative correlation between plant pigments and temperature. This was largely a distributional phenomenon associated with the fact that the deep water around Georges Bank had both a higher temperature and a smaller crop of plankton than the bank water. During the winter season the temperatures were more nearly uniform, and the correlations were insignificant. On combining the data from all the cruises, a seasonal relation was also apparent, with a correlation of — .360. The correlation between the mean temperature of the upper thirty meters and the total plant pigments in the vertical column was — .583. Both the seasonal and distributional relations of the plankton with temperature might be expected to be influenced by other factors, such as nutrients, which are also related to temperature and plankton. But the derivation of partial correlations in respect

to nitrate and phosphate shows that these substances were not responsible for the observed relation, but rather the correlation in the surface waters is increased to — .530, and in the areal estimate it is — .785.

The relationships of plankton and nutrients were highly complex. The correlations of both phosphate and nitrate with plant pigments were positive in September, January, and June, and negative in March, April, and May. Some of them were strikingly high, particularly the correlations of phosphate and pigments in September and April and of nitrate and pigments in January and March. Others, especially in May and June, were too low to be considered significant. The correlations of the total plant pigments in the vertical column with the nutrients in the upper thirty meters yielded the same results as the surface calculations with the single exception that the phosphate-pigment relation was negative in June. Correlations with the total nutrient content were similar to those in the upper thirty meters but of a lower order of magnitude.

The normal relationship between nutrients and plankton is supposed to be a negative one. The high nutrient concentration in winter is generally accompanied by a poor plankton crop, and the nutrients decline rapidly during the spring diatom burst. Thus it is not surprising to find in March a correlation of — .841 between plant pigments and nitrate, since we are comparing areas in which the spring bloom has developed vigorously, with an attendant decrease in nitrate, with other surrounding regions in which the bloom has not yet appeared.

The occurrence of positive correlations during the summer months and in January is indicative of the presence of other phenomena than the mere utilization-production relationship. The September and June correlations are simply mathematical statements of the fact noted in a previous section, that both plankton and nutrients showed a gradient between the shallow part of the bank and deeper water. For the presence of positive rather than negative relations, there seems no reasonable explanation other than that the balance between utilization and regeneration was in favor of the latter in shallow water. Why the same should not be true of the spring months is not quite clear, but the balance could be shifted by the influence of other factors, such as partial inhibition of regenerature by low temperature in the spring time, rapid consumption of the summer plankton crop by zoo-

plankton or inhibition of its growth by other chemical factors, or a combination of several such causes. Extension of these hypotheses would account also for the positive correlations of nutrients with plankton during the January cruise. In this case it is again reasonable to suppose that an inhibition of plankton growth occurs, this time because of the mid-winter minimum in solar radiation. It is then necessary to assume only that a favorable quantity of nutrients can ameliorate slightly the inhibiting effect of light.

When all the data are combined into a comparison of the seasonal relationships of plankton and nutrients, the correlations, both at the surface and in the areal estimate, are negative. The partial correlations, with the effect of the other two factors (temperature and the other nutrient) eliminated are as follows: at the surface, phosphate and plant pigments, — .291; nitrate-pigments, — .412; for the entire column, phosphate-plant pigments, — .668; nitrate-plant pigments, — .020.

The equations representing the relationship of temperature, phosphate, and nitrate with plant pigments are as follows:

$$PP = -1350\,t - 9700\,P - 2000\,N + 42180 \qquad (4)^*$$

where PP is Harvey units of plant pigments per m^3 at the surface, t is temperature, P is mg.-atoms of phosphate P per m^3 at the surface, and N is mg.-atoms of nitrate N per m^3.

$$PP = -130\,t - 50.9\,P - .175\,N + 2985 \qquad (5)$$

where PP is thousands of Harvey units per m^2 of sea surface (entire vertical column), t is temperature, P is mg.-atoms of P per m^2 in the upper 30 m., and N is mg.-atoms of N in the upper 30 m.

The multiple correlation coefficient for the combined effect of all the factors in equation (4) is .589, and for (5) it is .797. Both correlations are highly significant statistically and are of sufficient accuracy to be used as rough prediction mechanisms. The second

* The functions in this and the following equations are developed by standard mathematical procedures from the correlations and standard deviations of the variables. Thus the size of the function depends on the degree of variation of the variable as well as its relationship with the dependent variable. The latter is more easily evaluated, as indicated in the above discussion, by examining the partial correlations. For further explanation of these principles the reader is referred to a previous paper (Riley, 1939a).

is significantly higher than the first. As will be seen later, this is not the only calculation in which the areal estimate yields a higher correlation than the surface, and the reason for the difference probably lies in the fact that the summation of several analyses in the vertical column tends to smooth out sampling and analytical errors.

It is acknowledged that these equations are highly empirical. They take no account of certain other factors that might be important. Moreover, the factors are of unequal theoretical importance. Temperature is certainly a valid factor, for its effect, whether direct or indirect, is a matter of causal significance. Nutrients would belong in the same category if their effects were positive. However, the negative relationships obtained here do not represent simple causality, but rather are interdependent processes working in opposite directions, which would have no mathematical significance if the proper factor were included. In regard to the latter it may be said that although the absorption of nutrients and the coincident plankton production are dependent on the concentration of nutrients in the free water, the quantity of plankton present at a given moment is the result of a cumulative process extending through a considerable period of time, and is therefore directly correlated not with the momentary concentration but with the total availability of nutrients during the period in question. For example, the total availability of the nutrients during the spring diatom burst is the concentration at the beginning of the burst plus the amount regenerated during its course. The total amount of plankton present at the peak of the burst corresponds roughly to the initial concentration. The nutrient concentration during the bloom logically corresponds to the rate of plankton production (barring other limiting factors), and at the peak both become stabilized momentarily at a low level. Thus a direct relation between nutrients and plankton is not expected in a homogeneous association. It may occur in comparisons of different associations when the concentration differs greatly or when some other factor acts as a partial inhibitor of plankton growth. The latter is believed to be responsible for the positive correlations obtained during the September, January, and June cruises.

The failure to include light in these equations is a serious deficiency. No measurements were made which could be used for this purpose. A rough comparison can be made, however, by using Kimball's (1928) data, which give the normal total radiation for this area for every

month in the year. When the average plankton crop obtained on each cruise is correlated with the normal total radiation for that time of the year, the correlation between surface plankton and light is .314, and between total plankton and light is .396. The partial correlations in respect to temperature are .437 and .510 respectively. The multiple correlation coefficients of the combined effects of light and temperature are .538 for surface plankton and .604 for the total crop. Thus it is evident that not only is light an important factor, but also light and temperature alone, irrespective of independent variations in the availability of nutrients, account for a considerable part of the variations in phytoplankton on Georges Bank.

The Relation of Oxygen Production and Percent Saturation to Environmental Factors

The experimental determinations of oxygen productions showed pronounced direct relationships with plant pigments during every cruise except the January one. The highest correlation, .784, was obtained during the March cruise; the combined data gave a seasonal correlation of .764. The effect of temperature was slightly negative, and this was both a seasonal and a distributional phenomenon. The correlation for the entire set of data was —.328, which is rather low but statistically significant. The relationship of oxygen production with nutrients, like that of plant pigments and nutrients, was predominantly positive during the September, January, and June cruises, and negative the remainder of the time. Part of this relationship was due to the strong intercorrelation with plant pigments; thus the complete set of phosphate-oxygen production data showed a partial correlation in respect to temperature, plant pigments, and nitrate of 0.055, which was negligibly small, and the nitrate partial correlation, —.215, was only slightly significant. The coefficient of multiple correlation, representing the combined relation of all these factors with oxygen production was .778, which is not significantly better than the simple correlation with plant pigments.

But any analysis of photosynthetic activity which neglects the influence of light is open to criticism. Referring again to the data given by Kimball (1928) for the average radiation in the Georges Bank area and to the averages obtained on the several cruises, it is found that the correlation between oxygen production and total radiation

is .392, and the partial correlation between these two variables in respect to temperature is .532. Temperature again has a negative effect of course. The combined effects of temperature and light on oxygen production yield a correlation of .617, which is high enough to indicate that physical factors alone can be used to predict the photosynthetic rate in the Georges Bank region, although the resulting prediction is far less exact than when the phytoplankton is included in the estimate. The multiple correlation coefficient for the effects of light, temperature, and plant pigments on oxygen production is .940.

During the spring diatom burst there was a high degree of relationship between the percent saturation of oxygen in the surface water and the experimental values for oxygen production. In March the correlation was .926. During September, January, May, and June the correlations were insignificantly small. When all the cruises were combined the correlation was .490. These relationships are distinct enough to indicate that the variations in percent saturation of oxygen are to a large degree controlled by changes in the photosynthetic rate. Random variations in the saturation value are introduced by differences in the degree of vertical mixing, and in the experimental results by changes in the environment during the course of the experiment. These errors are largely eliminated by dealing with the averages for the different cruises, and the correlation between the average percent saturation of oxygen and the average experimental values for each of the six cruises is .796.

The percent saturation, like the oxygen production experiments, was inversely related with temperature and nutrients and directly related with plant pigments. The latter, with a correlation coefficient of .408, was somewhat lower than the plant pigment-photosynthesis correlation. The multiple correlation coefficient for the combined effect of temperature, nutrients, and plant pigments on the percent saturation of oxygen was .624.

The correlation between solar radiation and the average percent saturation for each cruise was .810, which is much higher than the light-oxygen production correlation. There are two reasons for such a difference. First, the heating effect of direct radiation increases the percent saturation, a purely physical phenomenon having nothing to do with biological events, which decreases the biological significance of the correlation. In the second place, since the surface water is partly derived from lower levels by turbulence, its oxygen content

is partly dependent on processes occurring in these lower waters. It is therefore reasonable to suppose that the limiting effect of low light intensities, which is least apparent at the surface and most marked near the limit of light penetration, would have a stronger controlling effect on the percent saturation than on the surface experiments.

Largely because of the high correlation with light, the percent saturation can be predicted with a considerable degree of accuracy. The correlation coefficient for the effect of light and temperature is .878, and with plant pigments included it becomes .950.

The areal estimate of oxygen production, stated as in a previous section as grams of oxygen per m^2 in excess of saturation, showed variations which were similar to the surface oxygen. Again there was a strong positive relation with plant pigments and with light, and negative correlations of lesser magnitude with temperature and nutrients. The coefficients of multiple correlation were as follows: oxygen with plant pigments, temperature, phosphate and nitrate, .755; with light and temperature, .762, and with light, temperature, and plant pigments, .887.

Regression equations expressing the relationships of oxygen production, both experimental and in the natural water are listed as follows:

Group 1, based on cruise averages.

$$OP = 0.00153\ L - 0.0355\ t + .064 \tag{6}$$

$$OP = 0.00205\ L - 0.0353\ t + 0.0000292\ PP - .505 \tag{7}$$

$$OS = 0.0466\ L - 0.62\ t + 92 \tag{8}$$

$$OS = 0.0479\ L - 0.25\ t + 0.000437\ PP + 83 \tag{9}$$

OP is oxygen production at the surface in grams per m^3 per day, OS is the percent saturation of oxygen in the surface water, L is gram cal. of solar radiation per cm^2 per day, t is temperature, and PP is Harvey units of plant pigments per m^3 at the surface.

$$OE = 0.1005\ L - 2.14\ t - 3.8 \tag{10}$$

$$OE = 0.0852\ L - 1.45\ t + 0.016\ PP - 16.9 \tag{11}$$

OE is grams of oxygen per m^2 in excess of saturation, L is g. cal. of solar radiation per cm^2 per day, t is the mean temperature in the upper 30 m., and PP is thousands of Harvey units per m^2.

Group 2, based on the individual analyses.

$$OP = -0.014\ t - 0.062\ P - 0.035\ N + 0.000022\ PP + 0.425 \quad (12)$$

$$OS = -0.312\ t - 6.04\ P - 0.015\ N + 0.000204\ PP + 109.5 \quad (13)$$

P is phosphate in mg.-atoms of P per m^3, N is nitrate in mg.-atoms of N per m^3 at the surface, and the other symbols are as in equations (6) to (9).

$$OE = -1.16\ t - 0.881\ P + 0.0693\ N + 0.00788\ PP + 26.6 \quad (14)$$

P is mg.-atoms of P in the upper 30 m., N is mg.-atoms of N in the upper 30 m., and the other symbols are as in equations (10) and (11).

The Seasonal Cycle

The two preceding sections have shown that variations in phytoplankton and gross productivity on Georges Bank, as expressed in terms of plant pigments and changes in oxygen in the experimental bottles and in the natural waters, were largely dependent upon variations in simple environmental factors—temperature, radiation, and nutrients. All the correlations between these biological variables and their combined environmental background were statistically significant, and in some cases the degree of relationship approached unity. It was evident, however, from the differences in correlations obtained on successive cruises that there were many special phenomena involved which prevented any attempt to explain the plankton growth adequately in a single equation. The purpose of the present section is therefore to discuss special interrelations and to explain further the meaning of the observed correlations.

a. The mid-winter minimum.

Atkins (1928) showed that in the English Channel the mid-winter minimum in plankton coincided with the seasonal low in radiation and that the time when the spring increase began was correlated with seasonal increase in light. Marshall and Orr (1928) found by experimental means that not only was there sufficient light for plankton growth at the surface in mid-winter, but that on sunny days it might even be strong enough to inhibit growth. They suggested, however, that the length of day might be an important factor, particularly at lower levels.

Study of the Georges Bank data presents the following points on the subject of mid-winter minimum.

1. The plankton minimum on Georges Bank, as in many other regions, corresponded with the period when the total radiation was least. Moreover, there is no evidence that other factors were unfavorable at that time. The quantity of nutrients was very large; the temperature was intermediate and presumably had no inhibiting effect, since in the spring larger crops were found when the temperature was lower, and they persisted through and beyond the time when the temperature was passing through its January level.

2. The seasonal cycle of oxygen production at the surface was shown in a previous section to be directly related with solar radiation. Moreover, the correlation between light and the rate of oxygen production per unit of plant pigments was very high, .894. Thus there is no reason to doubt that the average amount of radiation during the January cruise was below the optimum, although on bright days it might have been, as Marshall and Orr suggest, more than sufficient.

3. The plankton during the January cruise differed markedly in its vertical distribution from that of any other cruise. The largest quantity was found at the surface, and even at ten meters there was a considerable decrease. This suggests that the rate of growth was greatest at or near the surface. The fact that temperature and salinity were moderately uniform to a depth of 30 to 50 m. indicates that considerable vertical mixing must have been taking place. Therefore the presence of a vertical gradient is indicative of a rather rapid rate of growth at the surface. The experimental evidence throws light on this conclusion. The average oxygen production during the January cruise was 36 mgs. per m^3 per day, and the respiration was 6 mgs. The difference between these two values, 30 mgs., represents 11 mgs. of carbon per day that were available for plankton production. The average carbon content of the plankton association, according to estimates derived in a previous section, was 51 mgs. Thus if all the carbon produced in a day's time were converted into plankton, the increment in the surface crop would be 22%; or to put it in another way, the surface crop could be reduced by vertical turbulence by one-fifth each day and still maintain itself.

4. The possible effects of vertical turbulence were discussed by Atkins (1928), but he considered it to be a minor factor because he

found no evidence of a relationship between the force of the wind and the time of the spring diatom burst. He maintained, however, as did Gran and Braarud (1935) that increased turbulence in the autumn is responsible for decreases in diatoms frequently noted at that time. The latter also showed that in the Bay of Fundy turbulence, combined with a high degree of turbidity which confined photosynthesis to the upper few meters, kept the plankton crop at a low level throughout the year. On Georges Bank there is no means of making a satisfactory quantitative analysis of the rate of mixing. It is obvious, however, that with an average rate of growth of a fifth of a crop per day at the surface, turbulence was the only means of preventing the formation of a surface diatom burst.

5. The form of the vertical curve of plant pigment concentration is good evidence that the zone of active growth was confined to the upper few meters, although no exact measurements were made. The surface light was below optimum as indicated by a photosynthetic rate about half as much as in September and March. Presumably, therefore, the effective penetration of light was also less. The difference in intensity was not of the order of magnitude described by Clarke (1938) for the Woods Hole area, since the transparency of the water in January, as indicated by Secchi disc readings, was about the same as in September; however, the length of daylight would be an important factor. This is clearly shown by the experiments of Marshall and Orr (1928) in Loch Striven. During the winter oxygen production occurred at the surface from six in the morning until six in the evening. At a depth of only six meters it was almost entirely limited to the period from nine until three, and the total was not much more than a tenth of the surface value. This was quite different from the summer period, when production occurred in significant quantities to a depth of 10 or 20 m. or more, and the amount at 6 m. was nearly as great as at the surface.

It appears therefore that the winter minimum in plankton production is due to two factors: first, the winter minimum in solar radiation decreases the rate of photosynthesis and narrows the phototrophic zone; second, in the surface layer where growth is moderately active the plankton crop does not achieve large proportions because of constant reduction by vertical turbulence.

b. The inception of the spring diatom burst.

It has been noted in certain areas that the beginning of the spring diatom burst is correlated with the vernal increase in radiation—either in the intensity of light or its duration or both. These include the English Channel (Atkins, 1928), the Clyde Sea (Marshall and Orr, 1928), Long Island Sound (Riley, 1941), and others. Thompson and Gilson (1937) point out, however, that "the influence of illumination is much complicated by the fact that both sunshine and length of day have to be taken into account, and by the effect of stormy weather, which greatly increases the loss of light at the surface. That light is not always the key factor is shown by the fact that the spring maximum occurs about the same time in the Gulf of Maine (Bigelow, 1926) as at Lofoten (B. Ruud, 1926) which is 18° farther north."

Moreover, Føyn (1929) found that the vernal increase on the Norwegian coast began near land and occurred somewhat later in deep water. Føyn suggested that this was due to liberation of nutrients near shore by the outpouring from the spring thaw, a theory that was later contested by Braarud and Klem (1931) but supported by Gran (1932) who suggested the importance of organic combinations of iron derived from the soil.

Bigelow (1926) had likewise shown that in the Gulf of Maine the spring bloom began near shore while the deeper waters off shore still had their meagre winter crop. But he also demonstrated early spring bursts in the shallow, offshore waters of Georges Bank. The latter phenomenon is abundantly confirmed in the present report.

Here, then, is a situation somewhat different from that on the Norwegian coast, which deserves critical analysis. Its general features may be described as follows:

Near the end of March the plankton crop had achieved large dimensions in the shallow water near the center of the bank. There, in water of less than 30 fathoms depth, the average surface concentration was about three times as much as in depths of 30 to 50 fathoms and about six times as much as the water beyond the 50-fathom contour. In the deep water there had been approximately a two-fold increase between the January and March cruises. The total plant pigments in the vertical column also showed a gradient from the center of the bank outwards.

Both nitrate and phosphate had decreased in the shallow water

where the increase in phytoplankton was greatest. Presumably the rate of supply of nutrients by regeneration was greatest in the shallow water. But as the concentration in solution rather than the total supply available determines the rate of utilization when the concentration is large, nutrients could hardly have been responsible for the observed difference in plant pigments.

The mean solar radiation had approximately doubled between January and March. During the same period the oxygen production had increased from 36 to 307 mgs. per m^3 at the surface, and the photosynthetic rate, as indicated by the quantity of oxygen produced per unit of plant pigments had increased from 12 to 23 mgs. per thousand units. Oxygen production showed a gradient from deep to shallow water similar to that of plant pigments. But the rate of production did not. The correlation of this ratio with the total quantity of plant pigments was insignificantly small. The localization of the diatom burst was not, therefore, dependent on a local increase in the photosynthetic rate.

There are a few other factors that might be mentioned. Temperature did not show a significant correlation with the plankton crop. Transparency was least where the crop was greatest, so that it was a hindering rather than a helping influence. The average radiation was presumably about the same over the whole of the bank. There is little probability that coastal influences had any effect; it is even less probable that they would have a localized influence.

Thus by a process of elimination it becomes apparent that most of the common factors are not related to the phenomenon in question. Two of them—nutrients and transparency—appear to be adverse influences. One factor, which shows a marked degree of relationship with the plankton crop, namely, the depth of water, is worthy of further analysis.

Gran and Braarud (1935) discussed in detail the effect of turbulence on the plankton of the Bay of Fundy. They pointed out that when the plankton population is at equilibrium its total photosynthetic rate is equal to its respiration rate. Under optimal light conditions photosynthesis exceeds respiration; frequently it is about five times as much. Thus in order to survive, a phytoplankton cell would have to be exposed to optimum light conditions one-fifth of the time, or to sub-optimal conditions a somewhat larger proportion. Therefore, Gran reasoned, the plankton crop was limited (excluding nutrient

effects, etc.) according to the ratio of the fraction of the crop in the phototrophic zone at any one time to the total crop.

In applying this theory to spring bloom conditions it is first desirable to determine something of the relations between photosynthesis and respiration on Georges Bank. The mean oxygen production at the surface was 23 mgs. per thousand units of plant pigments in March, which corresponds to 8.6 mgs. of carbon. The mean respiration in March was 137 mgs. per m^3 per day, but only part of it was actual phytoplankton respiration. A statistical estimate of that part may be derived according to the regression equation of plant pigments on oxygen consumption. It is

$$OC = 0.0042\ PP + 81 \tag{15}$$

where OC is oxygen consumption in mgs. per m^3 per day, and PP is thousands of units of plant pigments per m^3. According to the equation the mean phytoplankton respiration was 56 mgs. per day, and the rate was 4.2 mgs. per thousand units of plant pigments, which is equivalent to 1.6 mgs. of carbon.

The estimate obtained in a previous section of the carbon content of the plankton was 17 mgs. per thousand units of plant pigments. This makes the respiration value, 10% of the weight of the plants per day, appear rather high. But in the subsequent calculations the purpose is to compare the behavior of a particular crop of plankton in different physical circumstances. Thus it is ratios rather than absolute values that are of interest. A completely arbitrary set of values could be used without invalidating the application of the theory, but it seems desirable to keep as close to the facts as possible without making the solution too complex.

With the aid of these values and with certain simple assumptions it is possible to set up a series of examples to illustrate the effect of depth on the production of a spring diatom burst. The assumptions are:

1. The rates of photosynthesis and respiration are constant, and equal to those obtained experimentally in March.

2. Photosynthesis occurs in a surface layer, the thickness of which is defined in the example. Respiration occurs continuously, wherever the plankton may be.

3. Plankton productivity is defined as the difference between the carbon fixed by photosynthesis and that utilized in respiration. Thus

it is assumed that the excess of the former over the latter is all converted into new plankton organisms.

4. Plankton growth during the initial stages of a bloom takes place according to the compound interest formula

$$Qt = Qo\ e^{rt} \tag{16}$$

where Qo is the initial population, Qt is the population at the end of time t, and r is the rate of increase.

Given a flat calm, with no vertical circulation, and an initial plankton crop of 3000 units per m^3 (the mean January crop) growing at the surface at the rate described. This rate is determined from the productivity which is 8.6 — 1.6 or 7 mgs. of carbon per thousand units of plant pigments (per 17 mgs. of carbon) per day. At the end of a day ($t = 1$),

$$\begin{aligned} 24 &= 17e^{r} \\ 0.4343r &= \log_{10}24 - \log_{10}17 \\ r &= .345 \end{aligned}$$

Using this value of r, we find that the time required to produce a diatom burst in the surface water equivalent to the mean quantity found in March in the shallow water (30,400 units per m^3) is 6.8 days.

In an area twenty meters deep which is stirred continuously and completely so that the vertical distribution is always uniform, which has an initial uniform population of 3000 units per m^3, in which photosynthesis is confined to the upper ten meters where the mean rate is the same as that given above, the rate of production is less because each diatom is using carbon continuously and producing it only half the time. Performing the calculation in the same way it is found that the time required to produce a crop of 30,400 units is 8.2 days. When the depth is increased to 50 m., $t = 37$ days. Beyond this point t increases rapidly and reaches infinity at a depth of about 55 m., at which point respiration equals photosynthesis, and no growth can take place as long as vertical mixing is complete.

It is evident, however, from examination of the vertical curves for plant pigments and nutrients that continuous vertical circulation did not occur to any great degree below 50 m. These substances were fairly uniform to a depth of between 30 and 50 m., below which there were gradients indicating some mixing to a depth of a hundred meters or more. Storms were common during this period, and it is reasonable

to suppose that periods of calm weather with marked growth in the upper waters alternated with storms, when general circulation took place, and growth was greatly retarded.

As a final example, therefore, we postulate a situation that approximates natural conditions, although it is still somewhat over-simplified. Given a region in which the depth varies from 40 to 100 m. or more but in which the solar radiation and wind velocity are uniform over the entire area; a uniform concentration of plant pigments of 3000 units per m^3 in the upper 40 m. and uniform rates of photosynthesis and respiration which are quantitatively the same as in the previous examples; given a week of moderate weather in which the wind velocity and the tides are sufficient to produce complete circulation to a depth of 40 m., followed by a two days' storm which is of sufficient intensity to mix the water uniformly to a depth of 70 m., or, in deeper water, produces some circulation to a depth of 100 m. or more, but which is uniform in the upper 40 m. and is equivalent in the column below 40 m. to a uniform concentration to a depth of 70 m. (this approximates conditions observed during March in the deep water); let this storm be followed by another week of moderate weather, then another storm.

According to the terms of the example and the original assumptions, plankton growth takes place during the first week, resulting at the end of that time in a uniform concentration in the upper 40 m. of 8124 units per m^3. The storm that follows will have little or no effect on the 40 m. water. The plankton will continue to grow at the same rate and at the end of the storm the concentration will be 10,800 units of plant pigments per m^3. In waters of greater depth the concentration is reduced by vertical mixing. At 55 m. the resulting concentration will be 5910 units. At that depth photosynthesis just balances respiration, and no growth takes place during the storm. At greater depths the surface population is not large enough to balance the respiration of the whole association, and a loss of carbon results. At depths of 70 m. or more the loss would be 4.4% of the total carbon content of the population. Under the terms of the example the result would be an equal deficiency of carbon (storage reserves, perhaps) in each cell which must later be made up before active growth could begin again. In the natural environment, in which vertical circulation is generally not as complete as indicated here, some cells would have more abundant reserves than others, and the latter probably

would be depleted to the death point. Thus there would be a decrease in both food reserves and total population, both of which would retard the subsequent growth. But for purposes of simplicity it is assumed here that all the loss is represented by a 4.4% decrease in the population. Consequently, in the areas in which the depth is 70 m. or more, the population in the first forty meters has been reduced by vertical mixing from 8124 to 4642 and by respiration loss to 4438.

During the next period of moderate weather the population at the 40 m. station increases to 29,250 units, and in the storm that follows there is a further increase to 33,720 units per m^3 and a total crop of 1,349,000 units. At the 55 m. station the plankton increases during the week of good weather to 16,010 units in the upper 40 m. Below 40 m. the concentration is reduced by its respiratory needs (9.4% per day) from the initial value of 5910 to 2955 units. The storm produces a uniform concentration from surface to bottom of 12,450 units, or a total crop of 685,000. In a similar fashion the deep water station rises to 12,020 units in the surface layer and is reduced to 2290 units below 40 m., resulting after the storm in a surface concentration of 7475 and a total crop of 523,000 units. Thus at the end of eighteen days time values have been obtained which are of about the same order of magnitude and the same general proportions as the observed March crops.

In summarizing the examples we point out that vertical turbulence has a two-fold effect on plankton productivity. By removing part of the crop from the zone of active growth, the growth rate of the entire population is reduced, and furthermore, any part of the population which remains isolated from the phototrophic zone suffers depletion through the normal process of respiration. It follows that depth is an important factor when it limits the extent of vertical turbulence.

Lacking adequate knowledge of the total photosynthesis and respiration of the plankton, or of the magnitude and time relations of vertical mixing, it is impossible to carry the discussion further. The sequence of events could not have been exactly like that described, for the radiation was not constant. On the contrary, it increased gradually but irregularly. The amount of turbulence also would be far more variable than is indicated in the example. Thus there is no way of predicting how long it would take a diatom burst to arise by this means. But granting the original points: that the observed differences in the plankton crop were not due to gradients in nutrients, produc-

tion, or temperature, that the weather-radiation and wind—were approximately uniform over the entire area, and that depth was the only factor that showed a marked relation with the plant pigment gradient, it is not unreasonable to conclude from the discussion that depth could have been the controlling factor, that the observed differences in plankton concentration were of an order of magnitude that could have been obtained solely on the basis of differences in depth.

It seems most probable that this particular set of factors, the rates of photosynthesis and respiration, and the degree of vertical turbulence, are the controlling influence on plankton growth throughout the late autumn, winter, and early spring, when the quantities of nutrients and of animals are such that they can have little effect on the phytoplankton crop. It would be interesting to compare the January and March plankton on Georges Bank from this viewpoint, but lack of knowledge, particularly of the depth of the phototrophic zone, prevents it. However, if the latter were the same in both months, and the respiration rate were also similar (actually it was probably larger due to the higher temperature in January, although the total respiration was too small to be measured accurately by experimental means) then with the observed rate of photosynthetic activity in January a diatom burst would have been impossible in water of greater depth than 30 m. While this is entirely speculatory, it is interesting to note that in Long Island Sound, which has a mean depth of 20 m., a January bloom has been noted (Riley, 1941).

c. The April plankton.

At the last station of the March cruise, near the western edge of Georges Bank, the plant pigments measured 4000 units per m^3 at the surface. Fifteen days later, half a degree of latitude away, in the same depth of water, the concentration was 23,600 units. This was typical of what had been happening all over the bank. The diatom burst, beginning in the shallow water, had spread out to the edges of the bank, where now the total crop was as great, and the surface concentration was only slightly less than in the shallows. At only one station, to the northwest in the Gulf of Maine, was the plankton crop the same as in March.

The question arises as to whether or not the factors discussed in the previous section were still controlling plankton growth. This is best considered by continuing the example used previously for illus-

tration. In water of 70 m. or more the example was terminated at the point where the concentration in the upper 40 m. was 7475 units per m^3, and the total crop was 523,000 units. If the system continued at the same rate for sixteen days more, the total crop would be 1,550,000 units and the surface concentration 22,000. The former is three-fourths of the observed crop; the latter is of about the same order of magnitude. In the shallow water of 40 m., on the other hand, the concentration in the surface water after two weeks, according to the example, should have been 329,000 units per m^3 and the total crop 13,000,000 units, both of which are very much larger than the actual values. It is evident therefore that, speaking in relative terms, the growth rate had decreased in the shallow part of the bank, or had increased in the deeper water, or both. It is advisable to examine both of these possibilities.

There are several things that might have caused an increased rate of growth in the deep water. In the first place, the radiation had continued to increase, and with it the photosynthetic rate had risen from 23 to 28 mgs. of oxygen per thousand units of plant pigments. The respiration had increased little, if any, so that, given an equal degree of light penetration, the productivity should be greater. A decrease in turbulence would also increase the size of the crop. Two weeks of continuous growth with no mixing below 40 m. would result in a total crop of 2,200,000 units. However, at the current rate of warming it would have produced a temperature difference of two or three degrees between the upper 40 m. and the lower waters. The actual temperature distribution indicates that although mixing might have been retarded by the small temperature stratification at the surface, there was some vertical turbulence to a depth of at least 100 m. It is reasonable to conclude, therefore, that the productivity in deep water may have increased during early April, and if it did, it was due largely to an increase in the photosynthetic rate.

But a change in the photosynthetic rate would have an even greater effect on productivity in shallow water. Thus it is evident that if the theory is to have any validity it is necessary to postulate other factors which were largely operative in shallow water and had an inhibiting effect there. The most obvious factor is of course the depletion of nutrients. Theoretical considerations and experimentally observed facts both lead to the conclusion that the rate of growth is dependent on the concentration of nutrients, and a decrease in the

latter may retard productivity before the nutrients are completely exhausted. Therefore the presence of low nitrate values in the shallow water in March was indicative that the spring diatom burst was approaching its peak.

At first glance it appears odd that the photosynthetic rate at the surface should have continued to increase during a period when the rates of increase in plant pigments and of utilization of nutrients were slowing down. However, such an increase in photosynthesis does not necessarily imply that the whole association was producing carbon more rapidly. It is apparent upon examination of the data that there was a strong inverse relationship between the quantity of plankton and the Secchi disc readings. During the March cruise they varied from 5.5 to 8.5 m. in waters where plankton growth was abundant and were 12.5 to 19 m. elsewhere. In April there were further reductions, the lowest value being 3.5 m. Since the effect of transparency on light penetration is cumulative with depth (cf. Clarke, 1938), the result would be a marked reduction of the phototrophic zone. It is pertinent in this connection to note that Marshall and Orr (1928) found the compensation point to lie at a depth of five meters or less during the height of the spring diatom burst.

During the March cruise it was noted that large and readily observable diatoms such as Coscinodiscus remained in a uniform suspension in the experimental bottles. In April a large part of them sank to the bottom in the course of an hour or two. If this was a general phenomenon it was undoubtedly of prime importance in ending the spring diatom burst. It seems improbable that the small change in temperature that occurred between the March and April cruises would have much effect on the sinking rate; it is more likely that it was a physiological phenomenon. Much of the buoyancy of diatoms is dependent on their oil reserves. It is possible, therefore, that the decline in the total photosynthetic rate that is believed to have occurred in April served two purposes: that it not only decreased productivity directly, but also increased the sinking rate of the diatoms by causing a depletion of their food reserves.

The factors that are believed to limit plankton growth in shallow water are all dependent either on the total productivity or on the size of the standing crop. They would therefore be expected to limit growth in deep water too, but not until it had reached approximately the same proportions as in the shallows. Thus it is reasonable to find

little horizontal variation in plankton in such an area at the peak of the spring diatom burst.

d. The May plankton.

The May cruise was intermediate between spring and summer on Georges Bank. Patches of the spring diatom burst persisted in the shallows. In deeper water it had sunk to lower levels and had been largely replaced at the surface by a sparser crop of summer species. Physiological and ecological conditions may be summarized as follows:

1. Nitrate was not a limiting factor; probably phosphate was not either.

2. The total photosynthesis at the surface was about one-third of the April value. The photosynthetic rate was 36 mgs. of oxygen per day per thousand units of plant pigments; this was the highest rate observed on any of the cruises. The transparency had increased slightly since April, but not to a degree commensurate with the decrease in plankton. It is probable that enough planktogenic detritus remained from the spring bloom to inhibit light penetration. It is evident, however, that with a considerable increase in the photosynthetic rate, with a slight increase in transparency, and with more solar radiation available, the mean photosynthetic rate must have been greater than at the height of the bloom.

3. With both nutrients and the photosynthetic rate extremely favorable, there would undoubtedly have been a bloom crop in May had it not been for certain unfavorable factors: Indirect evidence derived from study of the nitrate and salinity indicates that much of the April crop must have been swept away by horizontal movements of water masses and replaced probably by a sparse crop from waters of intermediate depth in the Gulf of Maine. This would tend to decrease the total productivity for a short time, although it probably would increase the rate of production. In the second place, the rising temperature increased the respiratory rate of the phytoplankton, thus tending to counterbalance the favorable effect of a high photosynthetic rate. Finally, the vernal rise of zooplankton was making increasing inroads on the standing crop. Detailed analysis of the grazing effect, and of phytoplankton-zooplankton relations in general, is deferred to a subsequent publication.

In comparing the May plankton with that found during the June and September cruises, the chief difference, ecologically speaking, was

in relations with nutrients. The correlations discussed in a previous section indicated that N and P were both limiting factors later in the season. Thus in June and September the extremely favorable light conditions were opposed by adverse factors: low nutrient concentrations, large quantities of zooplankton, and high temperature. The latter acted directly through its effect on respiration and possibly on flotation, and indirectly by affecting vertical stability and zooplankton activity.

Productivity

Phytoplankton productivity is of course based fundamentally on photosynthetic activity. This value—termed gross productivity in previous papers of this series—is readily determined from the experiments. The total range of gross productivity in the entire series of experiments was 0–880 mgs. of carbon per m^3 per day, and the averages by cruises are shown in the first column of Table VI.

TABLE VI

PRODUCTIVITY ESTIMATES DERIVED FROM EXPERIMENTAL DATA

	Gross production at the surface (mgs. of C/m³/day)	*Estimated respiration (mgs. of C per m³ per day)*	*Phytoplankton production at the surface (mgs. of C/m³/day)*	*Total gross production (mgs. of C/m²/day)*	*Total respiration (mgs. of C/m²/day)*	*Total phytoplankton production (mgs. of C/m²/day)*
Sept.	56	10	46	840	700	140
Jan.	14	4	10	110	160	−50
Mar.	115	17	98	1270	1080	190
Apr.	395	49	346	3950	3000	950
May	122	12	110	1700	1140	540
June	90	11	79	1260	630	630

Lacking any knowledge of the vertical range of photosynthetic activity on Georges Bank, estimates of total gross production cannot be made without introducing some very arbitrary elements. The general features of the vertical curve are so well known, however, that the results of such estimates are of the right order of magnitude. It is known, for example, that the point of maximum photosynthetic activity varies from at or near the surface in the middle of the winter to a depth of five or ten meters in summer. The lower limit of photosynthesis occurs at the point where the light intensity is reduced

to about one percent of the surface value. This of course depends on the transparency. In the one experiment on Georges Bank it was between 30 and 40 m. Clarke and Oster (1934) found the limit to be between 40 and 50 m. in the Gulf of Maine. Between the point of maximum photosynthesis and its limit the decrease is exponential.

In making a rough estimate of the total photosynthesis on Georges Bank the following assumptions are made: the lower limit was about three times the average Secchi disc readings, which were 11 m. on the September cruise, 14 m. in January, 11 m. in March, 8 m. in April, and 10 m. in May and June. It was further assumed that during the January cruise the maximum photosynthesis occurred at the surface, that the other months it was somewhere below that point, so that in March and April the mean quantity in the upper five meters was equal to the surface value, and in September, May, and June the upper 10 m. The decrease below these points was exponential. The results of the calculations are shown in the fourth column of Table VI.

Obviously such arbitrary estimates have no value except in so far as they are supported by other observations. The calculations of gross production lead directly to determinations of phytoplankton production (i. e., that part of the carbon produced which is in excess of respiratory requirements and therefore can be used in the production of new material), and the estimates of phytoplankton production can be compared with observed changes in the natural waters.

The respiratory requirement of the phytoplankton is determined from the regression equation of plant pigments on oxygen consumption (using the combined data from all the cruises) which is

$$OC = 0.00349\ PP + 164 \qquad (17)$$

where OC is mgs. of oxygen consumption per day, and PP is units of plant pigments. The respiratory requirements calculated from this equation are shown in the second and fifth columns of Table VI, and the phytoplankton production, the difference between gross production and respiration, appear in columns three and six.

Further analysis of productivity is concerned with the observed changes in biological substances in the natural waters. It is chiefly the period of the spring increase in phytoplankton that is useful in this respect. Between the January and March cruises the total increase in phytoplankton was 12068 mgs. of carbon per m^2. Eighty days

elapsed between the middle of the two cruises so that the average increment in phytoplankton was 151 mgs. of carbon per m^2 per day. The decrease in nitrate during the same period was 179 mg.-atoms per m^2. Assuming a "normal" carbon-nitrogen ratio of 6 : 1 by weight, the decrease in nitrogen represented a net daily increment in the carbon content of the plankton association of 187 mgs. per m^2. In January the oxygen content of the water was below saturation. In March part of it was supersaturated, and the average quantity in excess of saturation was 8.43 g. per m^2. This represents an increase of 40 mgs. of carbon per m^2 per day. The latter, however, is a minimal estimate because oxygen production was partly responsible for raising the oxygen in the water to the saturation point. On the other hand, the total increase in the percent saturation of oxygen, which was equivalent to 580 mgs. of carbon per day, is far too large a figure because part of the increase during the period when the water was undersaturated was dependent on purely physical phenomena.

Thus during the period from January to March there are two estimates of phytoplankton productivity which lie between 150 and 190 mgs. of carbon per m^2 per day. The higher value also corresponds to the experimental estimate for March production. Three other determinations, the two based on the percent saturation of oxygen and the January experimental rate, range far above and below the middle group. It is therefore reasonable to say that the productivity during this period probably lay somewhere near the middle range, and the other estimates may be set as absolute maximum and minimum limits.

Between the March and April cruises there was an increase in the plankton crop of 25072 mgs. of carbon per m^2, a mean increment of 1003 mgs. per day. Further increases occurred in oxygen. The increase in the percent saturation corresponded to a production of 1202 mgs. of carbon per m^2 per day, and the increase in oxygen in excess of saturation corresponded to 488 mgs. of carbon. As in the previous period, the first is a maximal and the second a minimal estimate of productivity. There were decreases in nitrate and phosphate, which corresponded to 148 and 1580 mgs. of carbon respectively, but neither of these estimates is considered valid because the nitrate-salinity relations indicated that part of the changes were of physical rather than biological nature. Thus the productivity during the March-April period was probably about 1000 mgs. of carbon per m^2, which is in

agreement with two of the estimates, namely, the experimental determination of the April rate and the observed increase in plankton, and the total range of probability is between 500 and 1200 mgs.

The productivity during the remainder of the year is problematical. During January it was certainly low, though perhaps not negative, as Table VI indicates. During the summer months the evidence is conflicting. On the one hand there is the relatively static condition of the plankton crop and the percent saturation of oxygen, which would seem to argue in favor of low productivity. On the other hand there are rather high experimental values for these months. In between these two opposite viewpoints is one bit of evidence. During the period between the May and June cruises, when the stable system of summer currents was being established, and there was no evidence of mixing with other waters, the nitrate showed a total decrease of 154 mg.-atoms per m^2 which corresponded to a carbon production of 316 mgs. per m^2 per day, or slightly more than half the May-June level of production as indicated by oxygen experiments. On the whole, the change in nitrate and the experimental observations are better indices of productivity than the size of the plankton crop or the percent saturation of oxygen, because the latter could be accounted for as grazing phenomena.

In conclusion, therefore, it appears that the total productivity of Georges Bank reaches its lowest ebb sometime in midwinter and is practically zero at that time. The highest point, in April, is of the order of one gram of phytoplankton carbon per m^2 per day. In late spring and early summer the productivity is about 300 to 600 mgs., and in the early autumn and early spring it is probably of the order of 100 to 200 mgs.

The analysis of the photosynthetic rate on different parts of the bank and the study of the vertical and horizontal distribution of plant pigments indicates that the total productivity of the bank does not differ markedly from that of the surrounding deeper water except at the beginning and end of the spring bloom. There is, however, a great difference in the availability of phytoplankton food, because in the shallow water it not only occurs in larger concentrations, thus making zooplankton feeding more efficient than in the deeper water, but also a much larger quantity is found in the water immediately above the bottom, which is of great importance to the plankton-feeding benthonic fauna.

SUMMARY

1. An analysis was made of the methods of measuring phytoplankton by determining, in a series of net collections, the plant pigment and chlorophyll content, the number of cells, the cell volume calculated from the counts and measurements of the cells, the dry weight, and the weight of organic matter and ash. The correlations of these various determinations showed that plant pigments had the highest mean correlation with other types of measurements and therefore was the most nearly representative determination of phytoplankton. The correlations were used to develop conversion factors of one type of determination to another.

2. The main body of the work was concerned with the vertical and horizontal distribution of plant pigments, nitrate, phosphate, and oxygen on Georges Bank. During parts of two summers plant pigments occurred in moderately large concentrations in the upper 30–50 m. of the north-central part of the bank, and extending northeast and southwest of the central portion, parallel to the long axis of the bank. The concentration decreased gradually toward deeper water on all sides. In spite of the higher concentration in shallow water, the total quantity underlying a unit area was not markedly greater than in the surrounding deep water. During January the quantity of plant pigments was less than at any other time when analyses were made. It was largely concentrated in the surface layers, and the horizontal distribution was fairly uniform. The spring diatom burst probably began in March and lasted until May. It started in shallow water and reached large proportions there before the burst started in deeper water. It also lasted longer in shallow water, but at the height of the bloom the plankton concentration was only slightly greater than in the surrounding oceanic waters. The variations in the percent saturation of oxygen and in experimental determinations of oxygen production at the surface were similar to those of plant pigments. The largest concentrations of nitrate and phosphate were in the shallow water during the summer months. During the spring diatom burst there was a pronounced inverse relation between plant pigments and nutrients, with the smallest concentrations of the latter occurring in the central part of the bank. During January phosphate and nitrate occurred in large quantities, and the latter also increased in May, just after the spring diatom burst, a phenomenon probably associated with an influx of off-bank water.

3. Plant pigments, the percent saturation of oxygen, and the experimental determinations of oxygen production showed positive correlations with light and negative ones with temperature. The correlations of plant pigments with nutrients were positive during the summer months, and this is associated with the high rate of regeneration and vertical transport in shallow water. The predominant relation during most of the year, however, was the usual negative one. Nutrients showed similar but lesser correlations with changes in oxygen.

4. The seasonal cycle is discussed in detail. It is believed that during the late autumn, winter, and early spring the chief limiting factors are solar radiation and vertical turbulence. The depth of water is also important when it limits turbulence. This is believed to be the reason why the spring diatom burst began in the shallow central part of the bank. During the part of the year when the illumination is favorable the limiting factors appear to be nutrients, grazing, and high temperature. The latter decreases productivity by increasing the respiration rate of the phytoplankton, as well as increasing the rate of grazing and affecting flotation.

5. The mean standing crop of plankton on Georges Bank varied at different seasons of the year from about 2 to 39 grams of carbon per m^2 of sea surface. The mean total productivity probably varied from about zero to one gram per m^2 per day.

6. The total productivity of the bank is probably little more than that of the surrounding waters. The larger concentration of phytoplankton on the bank is believed to be important, however, in relation to the grazing efficiency of both zooplankton and plankton-feeding benthonic fauna.

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TABLE VII

ANALYSES ON GEORGES BANK

SEPTEMBER, 1939

Date, Hour, Location and Bottom Depth	*Depth of Sample*	*Temp. °C.*	*Oxygen CC/L*	*Oxygen % Sat.*	*P Mg.-At./m³*	*N Mg.-At./m³*	*Plant Pigments H. U. per m³*
Station 3629	1	16.72	5.75	101	.08	3.0	4000
9/7/39 2:00	10	17.37	5.69	101	.22	2.4	3700
41° 33′ N., 69° 04.5′ W.	30	9.74	6.85	106	.40	1.8	8700
130 meters	50	6.69	6.69	97	.65	1.8	12000
	100	4.50	6.02	82	1.05	4.3	2300
Station 3630	1	17.51	5.59	100	.06	3.5	3800
9/7/39 10:00	10	17.52	5.70	102	.12	4.3	2400
41° 11′ N., 68° 57′ W.	30	10.15	6.83	106	.53	3.1	5200
91 meters	50	5.76	6.12	87	.99	3.1	4500
Station 3631	1	15.43	5.96	102	.59	0.8	12000
9/7/39 15:00	10	15.33	6.07	104	.57	0.8	8400
40° 50.5′ N., 69° 04′ W.	30	13.57	5.84	97	.65	0.9	5100
70 meters	50	13.27	5.85	97	.87	1.1	5900
Station 3632	1	16.26	6.00	105	.24	2.4	12500
9/7/39 19:00	10	16.26	6.01	105	.25	2.0	11000
40° 34′ N., 68° 51′ W.	30	13.76	6.07	101	.49	8.1	11100
68 meters	50	10.84	5.76	91	.44	8.6	5100
Station 3633	1	19.06	5.51	101	.14	3.4	2900
9/8/39 1:00	10	19.03	5.55	101	.13	4.7	2600
40° 14′ N., 68° 52′ W.	30	15.50	6.47	111	.23	6.8	3600
95 meters	50	8.53	5.84	88	.91	9.6	2200
Station 3635	1	23.06	4.99	98	.08	0.9	1600
9/8/39 9:00	10	23.05	4.95	97	.10	0.7	1600
39° 57′ N., 68° 45′ W.	30	23.03	4.37	86	.19	0.8	2200
1737 meters	50	13.46	5.06	84	.73	1.2	3200
	100	12.40	4.26	69	1.86	4.2	1100
	200	10.57	3.29	52	1.97	3.5	700
Station 3638	1	20.10	5.37	100	.04	1.5	3300
9/9/39 5:00	10	20.07	5.34	99	.03	1.4	4900
40° 30′ N., 67° 34′ W.	30	9.78	5.93	92	.70	0.9	6700
140 meters	50	8.64	5.61	85	.86	4.0	2600
	100	9.34	4.79	74	1.19	6.5	1400
Station 3641	1	17.18	5.93	105	.27	3.4	5600
9/9/39 14:00	10	15.37	6.15	106	.44	4.4	8300
40° 53′ N., 67° 52.5′ W.	30	13.78	5.80	97	.64	4.4	5600
66 meters	50	11.17	5.72	91	.95	4.9	5600
Station 3642	1	16.26	5.77	101	.52	4.3	12400
9/9/39 21:00	10	16.28	5.82	102	.50	5.0	11100
41° 18′ N., 67° 37′ W.	30	16.23	5.73	100	.51	4.2	12000
40 meters							

TABLE VII—*Continued*

Date, Hour, Location and Bottom Depth	*Depth of Sample*	*Temp. °C.*	*Oxygen CC/L*	*Oxygen % Sat.*	*P Mg.-At./m³*	*N Mg.-At./m³*	*Plant Pigments H. U. per m³*
Station 3646	1	19.27	5.45	100	.25	1.6	2800
9/10/39 7:00	10	19.26	5.43	100	.16	3.5	5600
40° 45′ N., 67° 20′ W.	30	9.72	6.13	95	.65	4.6	7900
91 meters	50	8.42	5.86	88	1.27	8.9	5000
Station 3647	1	15.05	6.39	109	.44	0.7	7200
9/10/39 14:00	10	14.54	6.52	110	.44	1.1	9900
41° 03′ N., 66° 44′ W.	30	10.04	6.15	96	.85	2.4	9300
80 meters	50	7.63	5.97	88	1.27	2.4	4300
Station 3649	1	16.18	6.17	107	.77	1.1	4600
9/10/39 19:00	10	15.41	6.25	107	.59	1.4	5100
41° 16′ N., 66° 54.5′ W.	30	9.81	6.04	93	1.19	1.5	4300
70 meters	50	9.41	5.84	90	1.54	3.1	2900
Station 3651	1	14.24	6.00	101	.42	3.0	7200
9/10/39 23:00	10	14.19	6.01	101	.42	3.5	9100
41° 34′ N., 67° 10′ W.	30	13.94	6.09	102	.41	3.2	7100
53 meters							
Station 3654	1	16.03	6.00	104	.08	2.5	4200
9/11/39 9:00	10	15.05	6.18	105	.17	3.3	10500
41° 21′ N., 66° 25′ W.	30	7.43	5.95	88	.80	6.0	4600
95 meters	50	7.28	5.58	82	.89	4.3	3800
Station 3656	1	19.56	5.44	100	.03	6.6	2200
9/11/39 18:00	10	19.58	5.42	100	.10	5.5	3500
40° 59′ N , 66° 01′ W.	30	15.59	6.66	115	.21	6.1	4500
2420 meters	50	11.53	6.44	103	.81	6.8	4200
	100	8.47	5.15	78	1.53	12.7	1300
	200	8.33	4.13	62	2.3	19.0	1100
Station 3658	1	14.39	6.25	105	.19	2.3	12800
9/12/39 10:00	10	14.38	6.19	104	.23	4.3	11100
41° 49′ N., 66° 13′ W.	30	10.88	6.11	97	.76	7.8	6000
86 meters	50	8.00	6.00	90	.97	5.3	3200
Station 3660	1	16.25	5.80	101	.23	1.3	2200
9/13/39 1:00	10	16.28	5.71	100	.25	1.5	3500
42° 17′ N., 66° 15′ W.	30	16.23	5.74	100	.59	3.5	4200
228 meters	50	15.59	5.73	99	.45	4.8	2900
	100	4.96	6.20	87	1.28	6.3	2700
Station 3664	1	14.08	5.99	100	.69	2.5	17900
9/13/39 11:00	10	12.55	6.14	100	.84	1.8	13900
41° 50′ N., 66° 40′ W.	30	12.35	6.01	98	.76	4.3	12000
76 meters							
Station 3666	1	13.25	5.98	99	.67	8.3	11100
9/13/39 21:00	10	13.29	6.01	99	.71	6.7	11900
42° 06′ N., 67° 02′ W.	30	13.22	5.97	99	.71	8.3	11500
60 meters							

TABLE VII—*Continued*

Date, Hour, Location and Bottom Depth	*Depth of Sample*	*Temp. °C.*	*Oxygen CC/L*	*Oxygen % Sat.*	*P Mg.-At./m³*	*N Mg.-At./m³*	*Plant Pigments H. U. per m³*
Station 3668	1	15.95	5.93	103	.28	8.6	3300
9/14/39 4:00	10	15.85	5.90	103	.25	8.3	4100
42° 24′ N., 67° 11′ W.	30	14.81	6.01	102	.28	7.9	7000
274 meters	50	13.38	6.15	102	.51	10.4	5900
	100	7.39	5.83	86	1.48	11.6	3800
	200	7.69	4.70	70	1.96	11.9	1800
Station 3670	1	15.42	5.88	101	1.04	7.5	12600
9/14/39 15:00	10	15.38	5.87	101	.97	16.0	12800
41° 46′ N., 67° 20 W.	30	15.33	5.85	100	1.15	15.3	13700
51 meters							
Station 3672	1	16.05	6.11	106	.29	8.3	8300
9/14/39 22:00	10	16.03	6.08	106	.29	10.4	7400
42° 02′ N., 67° 39′ W.	30	14.01	6.14	103	.56	12.2	12800
86 meters	50	12.26	6.15	98	.70	14.0	9100
Station 3673	1	14.03	6.10	102	.70	9.7	13600
9/15/39 4:00	10	13.82	6.18	103	.81	14.1	14700
41° 51′ N., 68° 05′ W.	30	11.72	5.99	96	.99	12.2	9000
64 meters	50	8.08	5.98	89	1.46	16.3	5300
Station 3674	1	16.38	5.88	103	.43	6.6	7300
9/15/39 14:00	10	14.88	6.07	103	.65	7.1	11200
41° 39′ N., 68° 36′ W.	30	11.16	5.95	95	1.21	6.4	7300
173 meters	50	8.74	5.97	90	1.46	7.3	6600
	100	6.27	5.94	85	1.63	11.6	4400
Station 3678	1	16.21	5.68	99	.51	7.6	16300
9/15/39 23:00	10	16.15	5.72	99	.56	7.8	15400
41° 06.5′ N., 68° 11.5′ W.	30	16.12	5.52	96	.61	8.4	13400
51 meters							
Station 3679	1	14.55	5.78	98	.65	9.2	10100
9/16/39 5:00	10	14.54	5.77	98	.65	9.4	10600
40° 50′ N., 68° 32′ W.	30	14.12	5.82	98	.70	8.9	11900
51 meters							
JANUARY, 1940							
Station 3726	1	5.24	6.75	94	1.80	8.2	3500
1/4/40 23:00	10	5.25	6.47	90	1.65	5.5	1600
41° 30′ N., 69° 13′ W.	30	5.24	6.56	91	1.72	5.1	1700
157 meters	50	5.22	6.53	91	1.54	5.5	1300
	100	5.19	6.53	91	1.84	5.6	200
Station 3728	1	5.06	6.68	92	1.61	5.2	1900
1/5/40 11:00	10	5.08	6.74	93	1.65	5.6	1800
40° 56′ N., 68° 55′ W.	30	5.06	6.75	93	1.50	5.5	1000
79 meters	50	5.06	6.74	93	2.02	7.9	900

TABLE VII — *Continued*

Date, Hour, Location and Bottom Depth	*Depth of Sample*	*Temp. °C.*	*Oxygen CC/L*	*Oxygen % Sat.*	*P Mg.-At./m³*	*N Mg.-At./m³*	*Plant Pigments H. U. per m³*
Station 3730	1	6.08	6.64	94	.97	8.1	3000
1/5/40 22:00	10	6.06	6.64	94	1.00	12.0	3000
40° 40′ N., 68° 29′ W.	30	6.04	6.65	94	1.67	10.4	2400
55 meters							
Station 3733	1	4.61	6.91	94	1.52	12.3	6400
1/6/40 10:30	10	4.63	6.90	94	1.69	3.1	5600
41° 02.5′ N , 67° 40′ W.	30	4.62	6.85	94	1.89	4.8	2900
57 meters							
Station 3734	1	4.38	6.93	95	.98	8.2	3800
1/7/40 24:00	10	4.42	7.00	95	.93	7.9	1400
41° 12′ N., 67° 16′ W.	30	4.42	6.99	95	.93	6.0	600
56 meters							
Station 3736	1	4.55	6.85	94	.93	5.4	1800
1/8/40 10:30	10	4.56	6.89	94	.96	4.1	700
41° 41′ N., 66° 38′ W.	30	4.56	6.92	95	.96	4.6	600
71 meters	50	4.55	6.89	94	1.04	8.2	300
Station 3738	1	3.48	7.16	95	.77	7.4	1700
1/8/40 21:00	10	3.50	7.15	95	.77	6.9	1400
42° 03′ N., 66° 11′ W.	30	3.73	7.02	93	.84	9.1	800
91 meters	50	5.51	6.15	86	1.20	8.6	400
Station 3740	1	3.32	7.16	94	.69	8.6	2000
1/10/40 3:00	10	3.34	7.22	95	.64	6.3	1000
42° 16′ N., 67° 00′ W.	30	3.35	7.28	96	.69	5.3	700
232 meters	50	5.39	6.38	89	.87	11.2	300
	100	6.84	4.32	62	1.05	15.4	400
	200	7.19	5.02	74	1.48	16.6	<100
Station 3742	1	4.32	7.02	95	.92	7.7	2000
1/10/40 13:00	10	4.32	7.02	95	.97	8.6	500
41° 45′ N., 66° 46′ W.	30	4.30	6.94	94	1.05	5.3	600
69 meters	50	4.30	6.87	93	1.05	6.1	600
Station 3744	1	4.68	6.87	94	1.11	8.4	3900
1/10/40 22:00	10	4.69	6.97	96	.98	8.7	2800
41° 08′ N., 66° 50′ W.	30	4.66	7.00	96	.98	8.7	2200
64 meters	50	4.66	6.85	94	.95	15.2	2200
Station 3746	1	4.84	6.99	96	.79	9.6	3000
1/11/40 8:00	10	4.84	6.92	95	.77	6.1	2500
40° 41′ N., 66° 39′ W.	30	5.74	6.85	96	.69	8.4	2000
1372 meters	50	6.41	6.68	95	.77	6.8	1700
	100	13.33	5.30	89	.66	9.0	800
	200	8.84	3.68	56	2.00	17.3	700

TABLE VII—*Continued*

MARCH, 1940

Date, Hour, Location and Bottom Depth	*Depth of Sample*	*Temp. °C.*	*Oxygen CC/L*	*Oxygen % Sat.*	*P Mg.-At./m³*	*N Mg.-At./m³*	*Plant Pigments H. U. per m³*
Station 3797	1	2.91	7.35	97	1.27	8.6	3300
3/25/40 15:00	10	2.96	7.35	97	1.41	8.4	3300
40° 26′ N., 67° 26′ W.	30	3.21	7.47	99	1.41	8.5	3900
164 meters	50	5.73	5.64	80	1.30	5.1	1900
	100	10.82	6.58	104	1.11	6.4	1300
Station 3798	1	2.30	8.20	106	1.14	1.9	56000
3/26/40 11:00	10	2.31	8.16	106	1.08	1.1	52000
41° 20′ N., 67° 36′ W.	30	2.30	8.05	104	.97	1.8	68500
42 meters							
Station 3800	1	2.78	7.58	99	.97	9.5	5500
3/26/40 20:00	10	2.75	7.53	99	.89	5.1	5500
40° 50′ N., 67° 12′ W.	30	2.78	7.60	100	.92	7.3	4100
95 meters	50	2.78	7.48	98	.94	4.2	3200
Station 3802	1	2.50	8.02	104	.77	1.9	30000
3/27/40 6:00	10	2.48	7.97	104	.79	1.5	35800
41° 15′ N., 67° 00′ W.	30	2.48	7.92	103	.84	2.4	28700
68 meters	50	2.48	7.98	104	.87	1.2	34400
Station 3805	1	2.91	7.63	99	.97	4.9	8200
3/27/40 24:00	10	2.88	7.60	99	.97	6.0	7300
41° 12′ N., 66° 11′ W.	30	2.92	7.62	99	.97	6.5	6600
713 meters	50	3.88	7.07	—	1.17	6.6	2900
	100	9.70	5.80	—	1.19	7.6	800
	200	6.31	4.42	—	1.61	9.5	400
Station 3807	1	2.73	7.59	99	1.05	4.3	10300
3/28/40 8:00	10	2.72	7.60	99	1.11	4.6	10200
41° 31′ N., 66° 27′ W.	30	2.75	7.60	99	1.16	5.4	9300
90 meters	50	2.77	7.56	99	1.16	4.9	8900
Station 3811	1	1.42	7.85	99	.89	5.6	5300
3/29/40 7:00	10	1.40	7.82	99	1.10	5.4	5200
42° 13′ N., 66° 26′ W.	30	2.48	7.35	96	1.18	5.2	3100
223 meters	50	3.43	6.90	92	1.34	8.2	2100
	100	5.93	5.15	73	1.59	8.5	500
	200	6.77	4.58	67	1.80	23.4	600
Station 3813	1	2.71	7.74	101	1.02	5.4	8500
3/29/40 13:00	10	2.60	7.78	101	1.02	4.9	8700
41° 56′ N., 66° 34′ W.	30	2.57	7.68	100	1.02	4.4	8700
73 meters	50	2.57	7.66	100	.99	4.4	12000
Station 3815	1	2.51	7.66	100	1.13	6.0	6600
3/29/40 21:00	10	2.48	7.68	100	1.16	6.0	7700
41° 55′ N., 66° 50′ W.	30	2.49	7.64	99	1.16	4.4	7200
49 meters							

TABLE VII—*Continued*

Date, Hour, Location and Bottom Depth	*Depth of Sample*	*Temp. °C.*	*Oxygen CC/L*	*Oxygen % Sat.*	*P Mg.-At./m³*	*N Mg.-At./m³*	*Plant Pigments H. U. per m³*
Station 3817	1	2.72	7.51	98	1.32	10.2	4400
3/30/40 6:00	10	2.68	7.51	98	1.38	7.9	3800
41° 52½′ N., 67° 25½′ W.	30	2.71	7.61	99	1.42	6.9	5300
57 meters.	50	2.71	7.60	99	1.71	7.4	7600
Station 3819	1	2.17	7.71	99	1.38	6.7	4700
3/30/40 13:00	10	2.11	7.73	100	1.32	7.4	3800
42° 08′ N., 67° 40½′ W.	30	1.95	7.69	99	1.38	8.5	2300
188 meters	50	2.31	7.55	98	1.47	5.9	2500
	100	3.78	7.01	94	1.77	6.5	700
Station 3822	1	2.65	7.46	97	1.46	8.2	2100
4/2/40 2:00	10	2.62	7.50	98	1.46	11.1	2100
41° 33′ N., 68° 30′ W.	30	2.61	7.48	98	1.46	10.1	1200
82 meters	50	2.62	7.49	98	1.57	10.9	1000
Station 3824	1	2.86	8.45	111	.81	5.0	28700
4/2/40 9:00	10	2.81	8.45	111	.84	3.8	30900
41° 09′ N., 68° 10′ W.	30	2.76	8.28	108	.84	4.5	36700
49 meters							
Station 3825	1	3.01	8.40	111	.88	3.3	21300
4/2/40 12:00	10	2.88	8.45	111	.92	5.9	22700
40° 56½′ N., 67° 57′ W.	30	2.74	8.24	108	.99	4.0	33100
57 meters	50	2.75	8.51	111	1.02	5.9	36400
Station 3826	1	2.92	7.55	99	1.79	8.2	4000
4/2/40 18:00	10	2.89	7.58	100	1.83	4.5	3300
41° 08′ N., 68° 45′ W.	30	2.90	7.59	100	1.75	7.9	1400
69 meters	50	2.90	7.56	99	2.27	8.2	700
APRIL, 1940.							
Station 3827	1	3.84	7.94	107	.83	5.2	23600
4/17/40 23:00	10	3.82	7.93	107	.81	4.6	23400
40° 37′ N., 68° 52′ W.	30	3.83	7.87	106	.81	5.1	24600
68 meters	50	3.80	7.94	107	.81	4.6	18900
Station 3828	1	3.72	8.83	118	.54	3.9	44500
4/18/40 6:00	10	3.73	8.83	118	.59	3.8	43900
40° 48′ N., 68° 25′ W.	30	3.75	8.79	117	.54	3.7	39800
51 meters							
Station 3829	1	3.77	8.74	117	.54	2.7	34200
4/18/40 12:00	10	3.77	8.76	118	.51	2.6	38400
41° 08′ N., 68° 09′ W.	30	3.78	8.77	118	.51	1.8	54600
48 meters							
Station 3831	1	3.68	8.22	110	.74	8.8	42400
4/18/40 22:00	10	3.62	8.19	109	.64	9.2	33600
40° 44′ N., 67° 46′ W.	30	3.44	8.03	107	.54	9.5	26700
69 meters	50	3.37	7.96	106	.64	11.1	27000

TABLE VII—*Continued*

Date, Hour, Location and Bottom Depth	*Depth of Sample*	*Temp. °C.*	*Oxygen CC/L*	*Oxygen % Sat.*	*P Mg.-At./m³*	*N Mg.-At./m³*	*Plant Pigments H. U. per m³*
Station 3833	1	4.74	8.42	116	.87	6.3	27200
4/19/40 7:00	10	4.75	8.43	116	.82	6.2	29400
40° 41′ N., 67° 03′ W.	30	5.61	6.85	96	.79	8.2	26000
117 meters	50	7.01	6.22	91	.97	24.1	14800
	100	11.23	4.64	74	.84	16.2	6800
Station 3835	1	3.81	8.99	121	.69	6.7	47800
4/19/40 16:00	10	3.72	8.65	116	.61	6.0	43000
41° 06′ N., 67° 26′ W.	30	3.71	8.75	117	.61	6.7	44000
59 meters	50	3.67	8.75	117	.64	8.5	26100
Station 3836	1	3.80	8.91	120	.27	2.1	49500
4/19/40 19:00	10	3.79	8.93	120	.27	2.6	54500
41° 16′ N., 67° 35′ W.	30	3.84	8.90	120	.27	1.7	47800
40 meters							
Station 3837	1	3.73	8.84	119	.45	2.5	65000
4/19/40 23:00	10	3.73	8.87	119	.45	4.4	66500
41° 27′ N., 67° 09′ W.	30	3.78	8.80	118	.47	3.0	61400
51 meters							
Station 3839	1	3.95	8.56	115	.43	2.4	53600
4/20/40 6:00	10	3.88	8.61	116	.45	1.9	66100
40° 56′ N., 66° 45′ W.	30	3.66	8.08	108	.54	4.1	47400
90 meters	50	3.70	7.40	99	.76	4.4	19400
Station 3841	1	3.52	8.68	115	.31	2.9	41900
4/20/40 19:00	10	3.53	8.71	116	.29	2.4	44800
41° 04′ N., 66° 07′ W.	30	3.24	8.23	109	.52	1.8	44500
2323 meters	50	3.49	7.06	94	.96	5.0	20100
	100	5.57	6.68	94	.85	5.1	15700
	200	10.87	4.15	66	1.41	22.0	3300
Station 3842	1	3.57	7.55	101	1.58	4.1	34700
4/24/40 23:00	10	3.64	7.41	99	.73	4.0	25000
41° 19′ N., 66° 16′ W.	30	3.76	7.25	97	.70	8.8	24500
97 meters	50	3.79	7.17	96	.76	5.7	22200
Station 3844	1	3.48	8.20	109	1.02	3.7	41600
4/25/40 9:00	10	3.47	8.15	108	.62	4.7	49500
41° 43′ N., 66° 40′ W.	30	3.46	8.09	108	.64	1.8	54400
69 meters	50	3.43	8.07	107	.62	3.6	58300
Station 3845	1	3.77	8.18	110	.91	2.1	35600
4/25/40 15:00	10	3.75	8.00	107	.76	3.7	44800
42° 09′ N., 67° 01′ W.	30	3.76	7.80	105	.76	4.7	38400
71 meters	50	3.71	7.73	104	.79	3.3	34500
Station 3846	1	3.69	7.84	105	1.43	2.6	28700
4/25/40 20:00	10	3.70	7.82	105	1.04	2.8	26400
41° 55′ N., 67° 29′ W.	30	3.72	7.73	104	1.02	4.0	25300
45 meters							

TABLE VII—*Continued*

Date, Hour, Location and Bottom Depth	*Depth of Sample*	*Temp. °C.*	*Oxygen CC/L*	*Oxygen % Sat.*	*P Mg.-At./m³*	*N Mg.-At./m³*	*Plant Pigments H. U. per m³*
Station 3848	1	3.51	7.45	99	1.76	3.2	4200
4/26/40 6:00	10	3.34	7.38	98	1.33	7.1	4200
41° 49½′ N., 68° 21′ W.	30	3.38	7.46	99	1.49	5.8	3500
216 meters	50	3.38	7.45	99	1.67	9.4	3500
	100	3.42	7.03	94	1.85	14.2	2900
	200	4.11	6.48	88	2.09	10.2	2500
Station 3849	1	4.63	9.16	125	1.13	2.8	12700
4/26/40 11:00	10	3.92	8.49	114	.93	3.5	49400
41° 33′ N., 68° 30′ W.	30	3.60	7.58	101	1.49	8.2	30500
91 meters	50	3.46	7.33	98	1.61	15.8	16700
Station 3850	1	4.30	8.25	112	.90	1.2	45600
4/26/40 16:00	10	4.27	8.17	111	.63	1.2	38300
41° 19½′ N., 68° 21′ W.	30	4.30	8.22	111	.78	1.7	44600
48 meters							
MAY, 1940.							
Station 3856	1	6.39	7.74	110	1.10	5.9	3500
5/9/40 10:00	10	5.01	7.91	109	.38	10.3	15300
40° 36′ N., 68° 52′ W.	30	4.67	7.87	108	.41	5.9	23000
68 meters	50	4.60	7.79	—	.41	6.8	28600
Station 3857	1	6.89	7.36	106	.53	9.2	1300
5/9/40 14:00	10	5.58	7.64	107	.48	8.7	700
40° 22½′ N., 68° 49½′ W.	30	3.93	7.51	101	.70	7.3	900
88 meters	50	3.95	7.30	99	.77	6.4	400
Station 3859	1	4.98	7.70	106	1.01	6.7	10800
5/9/40 22:00	10	4.98	7.75	107	.36	7.9	10900
40° 48′ N., 68° 24½′ W.	30	5.00	7.72	106	.38	6.4	13000
57 meters							
Station 3860	1	5.50	7.56	105	.60	8.9	22100
5/10/40 4:00	10	5.50	7.65	107	.43	11.1	26600
41° 03′ N., 68° 11½′ W.	30	5.52	7.57	105	.38	3.5	20100
44 meters							
Station 3861	1	5.31	8.05	112	.55	4.3	21600
5/10/40 8:00	10	5.29	8.09	112	.34	7.9	27100
40° 55′ N., 67° 55′ W.	30	5.33	8.04	112	.29	8.2	23400
54 meters							
Station 3863	1	7.15	8.04	116	1.46	9.4	3500
5/10/40 15:00	10	6.11	7.72	109	.43	5.8	6800
40° 33′ N., 67° 36′ W.	30	5.49	6.26	88	1.11	24.7	1400
117 meters	50	5.67	6.17	87	1.46	18.9	1100
	100	7.98	6.02	89	1.03	13.1	1000

TABLE VII—*Continued*

Date, Hour, Location and Bottom Depth	*Depth of Sample*	*Temp. °C.*	*Oxygen CC/L*	*Oxygen % Sat.*	*P Mg.-At./m³*	*N Mg.-At./m³*	*Plant Pigments H. U. per m³*
Station 3866	1	6.45	7.82	111	.92	11.6	1100
5/11/40 4:00	10	5.36	8.29	115	.53	14.7	1100
40° 53½′ N., 67° 15′ W.	30	4.17	7.77	105	.85	11.6	10500
84 meters	50	3.95	7.33	99	.96	5.4	11100
Station 3867	1	4.78	7.96	110	.63	9.4	4500
5/11/40 7:00	10	4.77	7.95	110	.55	12.1	8300
41° 05′ N., 67° 26′ W.	30	4.77	7.91	109	.48	9.3	9900
62 meters	50	4.73	7.90	109	.55	11.4	9500
Station 3868	1	5.32	8.26	115	.53	10.1	20200
5/11/40 12:00	10	5.30	8.27	115	.38	9.7	23500
41° 19′ N., 67° 39′ W.	30	5.29	8.20	114	.50	13.9	24000
40 meters							
Station 3869	1	5.02	8.37	116	.38	7.7	15700
5/11/40 19:00	10	5.03	8.35	116	.38	6.3	16600
41° 30′ N., 67° 09′ W.	30	5.05	8.41	116	.46	6.6	18600
51 meters							
Station 3871	1	5.50	8.35	116	.69	10.7	1600
5/12/40 3:00	10	5.35	8.41	117	.51	11.5	2900
41° 06′ N., 66° 50′ W.	30	4.20	8.19	110	.62	10.6	14700
73 meters	50	4.13	8.13	109	.62	9.4	19100
Station 3872	1	5.63	7.55	105	.77	9.9	4000
5/12/40 9:00	10	5.64	7.58	106	.49	9.6	3200
40° 50′ N., 66° 41′ W.	30	5.09	8.61	119	.55	11.5	25100
214 meters	50	4.50	6.85	94	1.08	12.5	11500
	100	5.63	5.95	84	1.18	19.2	2600
	200		4.33	—	1.40	15.5	300
Station 3874	1	5.00	7.91	109	.72	5.0	16100
5/13/40 22:00	10	5.00	7.97	110	.62	6.4	15900
41° 18′ N., 66° 20′ W.	30	4.58	7.61	104	.79	10.4	13300
99 meters	50	4.45	7.54	103	.84	10.3	15700
Station 3875	1	5.31	8.04	112	.60	3.5	10400
5/14/40 1:00	10	5.30	—	—	.51	5.1	11300
41° 31′ N., 66° 27′ W.	30	4.85	8.08	112	.70	6.7	26400
88 meters	50	4.79	8.01	110	.74	6.6	30800
Station 3876	1	4.74	8.12	111	.79	5.8	20200
5/14/40 4:00	10	4.74	8.18	112	.62	6.5	21200
41° 56′ N., 66° 32½′ W.	30	4.77	8.18	112	.65	11.0	18100
71 meters	50	4.72	8.21	113	.67	5.4	19600
Station 3878	1	4.37	7.82	106	.55	6.1	700
5/14/40 11:00	10	4.16	7.87	106	.43	5.7	700
42° 08′ N., 66° 23′ W.	30	4.38	7.81	106	.65	7.0	16700
99 meters	50	3.98	6.80	92	1.06	9.2	1700

TABLE VII—*Continued*

Date, Hour, Location and Bottom Depth	*Depth of Sample*	*Temp. °C.*	*Oxygen CC/L*	*Oxygen % Sat.*	*P Mg.-At./m³*	*N Mg.-At./m³*	*Plant Pigments H. U. per m³*
Station 3880	1	5.27	7.86	109	.69	4.5	11300
5/14/40 22:00	10	4.92	8.05	111	.58	11.0	13300
42° 09′ N., 67° 03′ W.	30	3.59	6.89	92	.95	20.0	3300
95 meters	50	4.01	6.36	86	1.15	21.9	600
Station 3882	1	6.76	7.78	111	.43	11.5	7300
5/15/40 7:00	10	5.80	7.85	111	.58	13.9	10300
41° 54′ N., 67° 54′ W.	30	5.01	7.74	107	.49	19.4	10600
69 meters	50	4.33	7.47	102	.72	13.9	7300
Station 3884	1	6.12	7.95	112	.41	4.4	6300
5/15/40 17:00	10	5.46	8.18	114	.35	8.7	8700
41° 33′ N., 68° 30′ W.	30	4.60	7.85	107	.60	6.5	11100
95 meters	50	4.23	—	—	.73	6.4	10900
Station 3886	1	5.16	7.78	108	.60	7.6	7100
5/16/40 1:00	10	5.16	7.82	108	.46	13.4	11200
41° 06′ N., 68° 38′ W.	30	5.19	7.80	108	.44	12.0	12000
62 meters	50	5.14	7.81	108	.57	6.7	10200
Station 3887	1	5.96	7.70	108	.52	5.9	700
5/16/40 4:00	10	5.95	7.74	109	.46	6.4	800
41° 09′ N., 68° 57′ W.	30	4.20	7.58	103	.73	16.5	500
97 meters	50	3.89	7.55	101	.90	4.9	300
JUNE, 1940							
Station 3932	1	12.83	6.80	110	.36	4.6	6800
6/19/40 17:00	10	12.81	6.83	111	.50	3.9	7200
40° 37′ N., 68° 52′ W.	30	7.16	7.05	102	.59	5.3	8300
69 meters	50	7.05	6.69	96	.75	16.3	1500
Station 3933	1	11.04	7.18	112	.80	7.6	7000
6/19/40 21:00	10	10.94	7.18	112	.55	8.6	6000
40° 22′ N., 68° 49′ W.	30	6.30	6.78	96	.91	9.8	1600
91 meters	50	5.43	6.60	92	1.23	12.2	1300
Station 3934	1	19.04	5.46	100	.18	5.8	1000
6/20/40 5:00	10	18.98	5.26	97	.32	4.8	1100
40° 19′ N., 68° 12′ W.	30	16.92	5.75	102	.27	7.7	1400
174 meters	50	12.02	6.42	104	.55	6.6	4600
	100	10.03	5.44	85	1.45	30.0	1100
Station 3935	1	11.41	6.92	109	.77	8.5	4300
6/20/40 9:00	10	9.08	7.40	111	.73	6.7	5700
40° 34′ N., 68° 17′ W.	30	5.93	7.04	99	1.43	7.3	1500
99 meters	50	5.27	6.78	94	1.39	25.0	1100
Station 3936	1	9.00	6.83	103	1.16	6.1	10900
6/20/40 14:00	10	8.56	6.89	103	1.11	6.4	14200
40° 48′ N., 68° 25′ W.	30	8.55	—	—	1.20	7.3	12900
49 meters							

TABLE VII—*Continued*

Date, Hour, Location and Bottom Depth	*Depth of Sample*	*Temp. °C.*	*Oxygen CC/L*	*Oxygen % Sat.*	*P Mg.-At./m³*	*N Mg.-At./m³*	*Plant Pigments H. U. per m³*
Station 3937	1	9.97	6.58	101	.37	5.5	16700
6/20/40 18:00	10	9.96	6.61	101	.43	9.6	14700
41° 07′ N., 68° 10′ W.	30	9.97	6.49	100	.51	6.4	14500
51 meters							
Station 3938	1	9.05	6.89	104	.53	3.7	17900
6/20/40 22:00	10	8.99	6.96	105	.55	5.2	15800
40° 56′ N., 67° 58′ W.	30	8.18	6.82	101	.73	8.9	11500
59 meters							
Station 3940	1	10.32	7.08	109	.47	7.2	2900
6/21/40 6:00	10	10.31	7.07	109	.45	4.2	2900
40° 31′ N., 67° 35′ W.	30	10.34	6.97	108	.43	4.9	9300
134 meters	50	6.27	6.10	87	.71	12.7	2500
	100	10.16	5.21	82	.75	13.8	1300
Station 3941	1	17.20	5.66	100	.31	6.8	1300
6/21/40 11:00	10	17.11	5.63	100	.28	5.5	700
40° 20′ N., 67° 21′ W.	30	13.38	6.42	106	.27	4.0	700
1401 meters	50	10.93	5.87	93	.68	7.3	1800
	100	11.73	5.36	86	.97	8.7	600
	200	11.56	4.94	71	1.19	21.6	300
Station 3942	1	10.25	7.21	111	.37	7.1	4100
6/21/40 16:00	10	9.11	7.38	111	.29	7.4	5000
40° 41′ N., 67° 02′ W.	30	11.16	6.60	104	.31	7.2	5600
132 meters	50	6.48	6.48	93	.83	12.9	2900
	100	6.05	6.11	87	1.07	13.1	1900
Station 3943	1	9.65	7.27	111	.44	6.6	16100
6/21/40 20:00	10	9.62	7.27	111	.56	5.9	16100
40° 53′ N., 67° 14′ W.	30	5.91	6.94	98	.92	10.7	2800
88 meters	50	5.84	6.94	98	1.00	10.4	1800
Station 3945	1	10.20	6.76	104	.39	6.9	10700
6/22/40 5:00	10	10.20	6.74	104	.37	6.8	21000
41° 18′ N., 67° 37′ W.	30	10.17	6.74	104	.36	4.2	28600
38 meters							
Station 3946	1	8.60			.44	6.7	12200
6/22/40 11:00	10	8.53			.42	5.3	13400
41° 32′ N., 67° 10′ W.	30	8.44			.44	6.3	15400
55 meters							
Station 3947	1	8.73	7.26	108	.74	.9	9200
6/22/40 18:00	10	8.55	7.13	106	.83	1.5	8800
41° 19′ N., 66° 57′ W.	30	8.06	7.11	105	.78	2.6	10000
66 meters	50	8.01	7.02	103	.87	1.8	8000
Station 3948	1	7.46	6.90	101	1.28	3.8	3600
6/22/40 23:00	10	7.32	6.98	101	1.19	4.1	4900
41° 06′ N., 66° 47′ W.	30	6.49	6.91	99	1.17	5.0	3200
75 meters	50	6.47	5.48	78	1.24	3.4	3200

TABLE VII—*Continued*

Date, Hour, Location and Bottom Depth	*Depth of Sample*	*Temp. °C.*	*Oxygen CC/L*	*Oxygen % Sat.*	*P Mg.-At./m³*	*N Mg.-At./m³*	*Plant Pigments H. U. per m³*
Station 3950	1	17.55	5.47	98	.41	2.6	1900
6/23/40 8:00	10	17.55	5.52	99	.37	3.0	2300
41° 07′ N., 66° 04′ W.	30	9.36	6.66	102	.78	2.3	7300
2213 meters	50	11.72	5.40	88	.96	4.1	2100
	100	12.38	5.03	82	1.67	5.2	1000
	200	11.27	5.71	91	2.36	14.0	300
Station 3951	1	8.33	7.88	116	.89	1.6	10300
6/23/40 17:00	10	7.94	7.62	111	.78	1.3	14100
41° 19′ N., 66° 16′ W.	30	6.80	6.46	93	.89	1.8	5200
106 meters	50	5.40	6.77	94	1.34	3.4	2100
Station 3952	1	7.35	6.92	101	1.02	6.2	6000
6/23/40 22:00	10	7.24	6.85	99	1.02	4.8	5000
41° 31′ N., 66° 27′ W.	30	6.88	6.92	99	.98	3.7	5400
88 meters	50	6.85	6.90	99	1.15	3.7	6300
Station 3953	1	9.16	6.84	103	.56	2.4	6200
6/24/40 2:00	10	6.59	6.81	97	.85	2.3	3300
41° 46′ N., 66° 17′ W.	30	6.56	6.82	97	.93	2.3	3100
81 meters	50	6.58	6.90	98	.93	2.9	3400
Station 3954	1	10.70	6.37	99	.59	2.2	3900
6/24/40 7:00	10	7.74	7.16	104	.78	1.3	6900
42° 09′ N., 66° 30′ W.	30	4.29	6.89	93	1.28	4.2	2600
99 meters	50	3.86	6.56	88	1.50	7.0	2200
Station 3955	1	9.73	7.12	108	.80	2.3	4100
6/24/40 11:00	10	8.75	7.62	113	.93	2.1	5300
41° 55′ N., 66° 28′ W.	30	5.93	6.95	98	1.37	2.6	3900
86 meters	50	5.80	6.88	97	1.41	4.3	2700
Station 3956	1	—	7.22	—	1.26	2.0	8200
6/24/40 15:00	10	—	7.04	—	1.13	1.8	9300
41° 44′ N., 66° 37′ W.	30	—	7.10	—	1.17	3.4	7800
68 meters	50	—	7.05	—	1.17	3.7	6800
Station 3958	1	11.85	6.70	106	.33	7.5	4300
6/24/40 24:00	10	11.58	6.95	110	.31	7.3	3500
42° 18′ N., 67° 12′ W.	30	5.61	7.01	98	.71	6.1	4800
89 meters	50	5.56	7.00	98	.76	12.5	5700
Station 3959	1	9.66	7.24	110	.43	7.5	21400
6/25/40 6:00	10	9.65	7.08	108	.34	6.3	23600
41° 43′ N., 67° 18′ W.	30	9.55	7.24	110	.37	6.2	24800
53 meters							
Station 3960	1	9.34	6.73	102	.49	4.4	7700
6/25/40 9:00	10	9.31	6.77	102	.46	6.2	7000
41° 56′ N., 67° 30′ W.	30	8.92	6.73	101	.54	8.1	5900
49 meters							

TABLE VII—*Continued*

Date, Hour, Location and Bottom Depth	*Depth of Sample*	*Temp. °C.*	*Oxygen CC/L*	*Oxygen % Sat.*	*P Mg.-At./m³*	*N Mg.-At./m³*	*Plant Pigments H. U. per m³*
Station 3961	1	9.57	6.85	104	.51	7.5	13700
6/25/40 15:00	10	9.57	6.74	102	.44	5.9	14000
41° 54′ N., 67° 55′ W.	30	8.32	7.02	104	.53	3.9	7700
62 meters	50	7.71	6.63	97	.66	5.2	5700
Station 3963	1	12.59	6.42	103	.18	3.8	4700
6/26/40 5:00	10	11.74	6.63	105	.24	4.1	7300
41° 34′ N., 68° 31′ W.	30	6.40	7.06	100	.47	7.0	6000
117 meters	50	4.14	7.09	95	.69	4.9	2900
	100	3.19	7.00	93	.82	8.0	1800
Station 3964	1	9.50	6.70	102	1.25	5.6	11400
6/26/40 9:00	10	9.06	6.65	100	.47	4.2	9300
41° 21′ N., 68° 21′ W.	30	8.91	6.73	101	.44	3.5	7800
57 meters							
Station 3965	1	9.21	6.88	104	1.34	5.3	13600
6/26/40 15:00	10	9.17	6.86	104	.44	6.1	11100
41° 07′ N., 68° 40′ W.	30	9.12	6.94	104	.42	4.8	8500
60 meters	50	9.15	7.27	109	.60	3.9	9100
Station 3966	1	8.60	6.88	102	1.44	3.3	7000
6/26/40 19:00	10	8.63	6.91	103	.55	4.3	6800
41° 06½′ N., 68° 58½′ W.	30	7.82	6.86	100	.66	3.9	4800
84 meters	50	7.02	6.87	99	.73	3.9	4300

TABLE VIII

FURTHER ANALYSES ON GEORGES BANK SURFACE WATERS

Station	*O_2 Production G./M^3/Day*	*O_2 Consumption G./M^3/Day*	*Chlorophyll Mg./M^3*	*Secchi Disc*	*Station*	*O_2 Production G./M^3/Day*	*O_2 Consumption G./M^3/Day*	*Chlorophyll Mg./M^3*	*Secchi Disc*
3629	.32	.05	2.4		3824	1.34	.34	15.5	5.5
3630	.07	.91	2.0	10.5	3825	.76	.30	12.5	8.5
3631	.06	.11	3.7	8	3826	.05	.01	2.6	
3632	−.01	.62	4.1	6	3827	.16	.05	5.7	
3633	.02	.23	1.1		3828	1.20	.51	18.3	3.5
3635	.03	.00	.7	25	3829	1.85	.41	19.1	
3638	.25	.34	1.4		3831	1.06	.50	11.5	
3641	.15	.19	3.2	10	3833	.57	.22	11.7	
3642	.05	.08	3.4		3835	.50	.24	16.1	
3646	.04	−.06	1.0	11	3836	1.16	.21	15.8	
3647	.09	.23	3.0	9	3837	2.04	.18	27.2	
3649	−.22	.36	1.7	10	3839	1.15	.11	15.3	5.5
3651	.30	.23	2.1		3841	.68	.29	14.2	5.5
3654	.03	.13	1.7	13	3842	.82	.08	10.7	
3656	.14	.16	1.0	17.5	3844	1.14	.27	14.8	6
3658	.31	.27	4.0	8	3845	2.35	1.06	13.1	5
3660	.05	.16	1.2		3846	1.17	.05	10.0	
3664	.32	.51	4.7	8.5	3848	.06	.16	3.8	19.5
3666	.35	.11	3.4		3849	.73	.30	6.6	
3668	−.05	.12	1.1		3850	1.27	.26	21.6	
3670	.33	.17	3.8	9	3856	.02	.08	2.7	10
3672	.09	.27	1.7		3857	−.05	.06	1.3	18
3673	.33	.16	4.0		3859	.05	.04	6.2	
3674	.14	.16	2.7	9	3860	.20	.12	11.9	
3678	.49	.22	5.6		3861	.45	.13	12.7	4
3679	.20	.01	3.4		3863	.17	.15	5.5	8
3726	.06	.04	1.7		3866	.07	.18	1.2	16
3728	.04	−.03	1.3	11	3867	.10	.11	4.6	8
3730	−.04	.00	1.5		3868	.08	.20	11.5	
3733	.05	−.01	3.0	7	3869	.29	.16	9.4	4
3734	.07	.01	2.2		3871	−.09	.15	3.5	
3736	.02	.02	1.7	16	3872	.10	.01	2.8	
3738	.06	.03	1.0		3874	.76	.10	7.4	
3740	.10	.07	1.3		3875	.54	.12	6.0	
3742	.00	−.03	1.1	19	3876	1.71	.46	9.0	4
3744	.03	.00	1.8		3878	.25	.22	.6	11
3746	.01	−.03	1.4	20	3880	.61	.11	8.0	
3797	.05	.04	1.5	15	3882	.24	.15	6.7	10
3798	.86	.19	21.2	5.5	3884	.27	.09	3.8	8
3800	.12	.15	2.9		3886	.54	.38	4.8	
3802	.53	.25	15.2	6.5	3887	.50	.66	1.2	13
3805	.15	.08	4.0		3932	−.14	.18	2.9	9
3807	.11	.00	6.2		3933	.14	.61	5.9	
3811	.02	.14	2.7	19	3934	−.18	.14	1.2	14
3813	.48	.25	4.5	11	3935	.10	.24	3.9	10
3815	.03	.09	3.2		3936	1.12	.82	7.0	10
3817	.12	.07	2.1	12.5	3937	.22	.28	8.6	4.5
3819	−.03	.11	2.1	16.5	3938	1.16	1.19	7.1	
3822	.01	.03	1.6		3940	.17	.47	1.9	18

TABLE VIII—*Continued*

Station	*O_2 Production G./M³/ Day*	*O_2 Consumption G./M³/ Day*	*Chlorophyll Mg./M³*	*Secchi Disc*	*Station*	*O_2 Production G./M³/ Day*	*O_2 Consumption G./M³/ Day*	*Chlorophyll Mg./M³*	*Secchi Disc*
3941	.06	−.01	1.2	22	3954	.22	.20	2.5	11
3942	.20	.38	2.7	10	3955	.24	.18	1.7	11
3943	.20	.16	5.6		3956	.14	.32	5.9	11
3945	.10	.13	3.9	8	3958	.13	.12	2.3	
3946	.10	.14	5.3	11	3959	.38	.26	9.4	7
3947	.27	.33	6.0	11.5	3960	.17	−.02	3.7	8
3948	.11	.18	2.0		3961	.39	.08	6.5	5.5
3950	.51	.47	1.4	18	3963	.24	.02	2.4	8
3951	.45	.73	5.4	7.5	3964	.18	.08	5.6	9
3952	−.06	.26	3.8		3965	.04	.33	6.4	9
3953	.23	.21	3.5		3966	.31	.13	3.7	7.5

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Examples and Outline of Certain Modifications in Upper-Air Analysis

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ABSTRACT

The first part of this paper deals with methods of isentropic analysis based on the scaled values of data transmitted for the purpose by the United States Weather Bureau. The practical application of shear-stability ratio vectors is demonstrated. A logical order of analysis is presented, designed to make the fullest possible use of all data available. The preferred isopleths for direct representation are those of temperature, acceleration potential and specific humidity; a system of isopleth spacing convenient in conjunction with surface weather maps is employed.

In the second part the properties of various surfaces for upper-air analysis are systematically studied. It is found that severe restrictions exist in the use of surfaces of constant entropy or potential temperature. All the properties discussed are, however, adequately satisfied by a surface of constant potential virtual temperature, a quantity newly introduced and defined as the potential temperature of matter of standard composition, in this case dry air, at the same pressure and density as the sample. The thermodynamic configuration of this surface is described by isotherms of virtual temperature.

INTRODUCTION

ISENTROPIC ANALYSIS in this country originated with a particular purpose in view, namely, as a means of using moisture distribution to determine flow patterns in the atmosphere. It revealed, very successfully, certain theoretically anticipated patterns. Subsequently it has come into general use in connection with upper-air analysis, but for the most part its application is dominated by the original particular purpose. A rather different approach is to use isentropic analysis in a more purely descriptive fashion as the principal tool for upper-air analysis. This demands that an isentropic chart represent synoptically as much useful information as possible, and that all phases of its preparation receive due care.

As the second approach differs in some respects from the original one, methods of analysis are discussed and

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illustrated herein. In the second part of the paper some fundamental matters concerning upper-air analysis are presented.

Methods of Isentropic Analysis

It is of the utmost importance to determine as accurately as possible the configuration of an isentrope. The positions of its intersections with radiosonde ascents are known. At any radiosonde station where simultaneous measurements of upper-air winds are available the slope of the isentrope at the intersection is known if the flow is geostrophic—which appears to be a reasonable assumption except near the ground. The interpolation between radiosonde stations must be made by utilizing this information fully. On correct interpolation of the configuration depends the entry of winds from the proper elevation at the intervening pilot balloon stations. On it depends also the delineation of the saturation areas on an isentrope, and hence the location of the moisture lines. More fundamental is the intrinsic value of the configuration itself. Anomalies in the configuration are an important measure of weather, one which can be followed from day to day and one which must be forecast in conjunction with any other type of forecast.

Shear-Stability Ratio Vector

A convenient method was devised by Spilhaus[1] to use winds at radiosonde stations for finding the slope of an isentrope by means of the shear-stability ratio vector,

$$\mathbf{S} = \frac{1}{E}\frac{\partial \mathbf{v}}{\partial z}, \tag{1}$$

$\mathbf{v}$ being wind velocity, z the coordinate upward and E the stability. For a perfect gas having constant specific heat and of uniform composition the stability may be written in terms of potential temperature, so

$$\mathbf{S} = \frac{\partial \mathbf{v}}{\partial z}\Big/\frac{1}{\theta}\frac{\partial \theta}{\partial z} = \left(\frac{d\mathbf{v}}{d \ln \theta}\right)_{x, y, t}, \tag{2}$$

where x and y are the horizontal coordinates. Under the additional condition of geostropic flow the temperature gradient in an isentrope is related to the shear-stability ratio vector by

$$\mathbf{S} = \frac{c_p}{f}\,\mathbf{k} \times (\nabla T)_s, \tag{3}$$

c_p being specific heat at constant pressure and f the Coriolis parameter.

Acceleration Potential

The three essential meteorological variables on an isentrope are the thermodynamic state, the water vapor concentration and the flow. The last is represented with the help of the quantity, introduced by Montgomery,[2]

$$\Upsilon = \Phi + c_p T \tag{4}$$

where Φ is geopotential. There is considerable confusion over what to call this quantity.[3] It is commonly referred to erroneously as "stream function." Although it is related to the geostrophic wind somewhat in the manner of a stream function, its dimensions are not the same and the relation involves the variable Coriolis parameter. The terms "geostrophic potential"[4] and "isentropic geostrophic potential"[1] have been suggested, but these also are objectionable. A correct and convenient term for such quantities is *acceleration potential*, which may be preceded by *isobaric, isosteric, isothermal, isentropic*, etc., for the acceleration potential appropriate to each of these surfaces. The gradient in any surface of the appropriate acceleration potential is simply the negative force per unit mass associated with the horizontal pressure gradient. Thus, designating specific volume by α, pressure by p, the particular gas constant by R/m, one finds that

$$-\alpha[\nabla p]_\Phi = -[\nabla\Phi]_p = -[\nabla(\Phi + \alpha p)]_\alpha$$
$$= -\left[\nabla\left(\Phi + \frac{R}{m}T\ln\frac{p}{p_0}\right)\right]_T = -[\nabla(\Phi + c_p T)]_s. \tag{5}$$

(The last two forms rest on the assumptions of uniform composition and of perfect gas, the last form on the assumption of constant specific heat also.) It is therefore apparent that the terminology suggested is entirely suitable.

Choice of Thermodynamic Variable

On an isentrope in a medium of uniform composition the specific entropy and any other thermodynamic variable describe the thermodynamic state completely, so an isobar is also an isotherm, an isostere and an isopycnal. In a perfect gas, if c_v is the specific heat at constant volume and ρ is density, these variables are related by

$$dp = \frac{c_p}{\alpha} dT = -\frac{c_p}{c_v}\frac{p}{\alpha} d\alpha = \frac{c_p}{c_v}\frac{p}{\rho} d\rho. \qquad (6)$$

Since the change of one variable with any other is not constant the spacing of one family of isopleths drawn for equal increments differs from the spacing of any other family. The choice of thermodynamic variable for direct representation is thus essentially a choice of most convenient spacing.

Pressure, as suggested by Byers,[5] is the thermodynamic variable commonly used on isentropic charts. It is advantageous because the weight of air in unit vertical column between two surfaces is simply the pressure difference. But this advantage seems outweighed by the useful features of temperature:

(a) The shear-stability ratio vector is related directly to the temperature gradient.

(b) Temperature has inherent descriptive value. In particular the isotherm for 0°C has been advocated by Byers.[5]

(c) Temperature approximates to a linear function of geopotential. The relationship for a perfect gas of uniform composition is shown by

$$\left(\frac{dT}{d\Phi}\right)_{s,y,t} = -\frac{1}{c_p}\frac{\dfrac{\partial T}{\partial x} + \alpha\dfrac{\partial T}{\partial \Phi}\dfrac{\partial p}{\partial x}}{\dfrac{\partial T}{\partial x} - \dfrac{\alpha}{c_p}\dfrac{\partial p}{\partial x}} \qquad (7)$$

and a similar equation for the other component. Usually the terms involving horizontal pressure gradient are small compared with the horizontal temperature gradient. By letting the horizontal pressure gradient vanish the equations reduce to simply

$$\left(\frac{\nabla T}{\nabla \Phi}\right)_s = -\frac{1}{c_p}. \qquad (8)$$

The corresponding result for any other thermodynamic variable is not a constant.

(d) Geopotential on an isentropic surface may be determined more accurately than by the last method, for it is given precisely in terms of the field of a thermodynamic variable and of the field of the acceleration potential. The relation is far simplest in terms of the temperature field,

$$\Phi = \Upsilon - c_p T,$$

so that geopotential is found by mental subtraction to full accuracy.

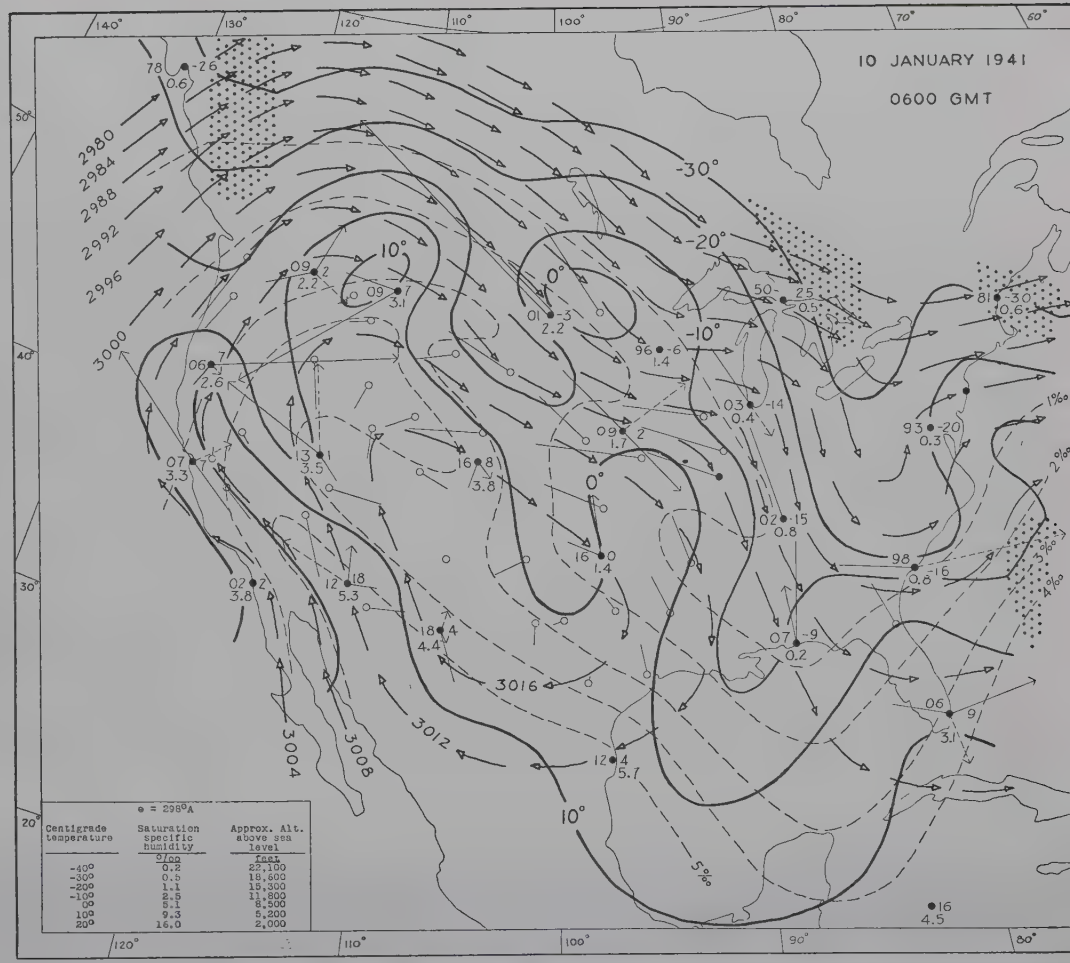
Isopleth Intervals

Accordingly the temperature field is chosen to represent the thermodynamic state, as shown in the accompanying illustration. Isotherms are drawn for each tenth degree centigrade, the shear-stability ratio vector being plotted so that its magnitude is the distance traveled in a quarter hour (14.4 minutes) at the speed of the vector. Isopleths of the acceleration potential, which may be loosely called *streamlines*, are drawn for each fourth megerg per gram, the observed wind being plotted vectorially to represent the distance traveled in six hours* at the velocity of the wind. These intervals are chosen in conjunction with isobars for each fifth millibar on the surface weather map so that for all three purposes (if the density at the ground is $1.25 \cdot 10^{-3}$ g cm^{-3}, or the virtua temperature is 6°C at 1000 mb) the hyperbolic parameter relating the isopleth spacing to the appropriate vector is the same function of latitude. The rational choice of spacing which permits the use of a single hyperbolic parameter for all families is of considerable convenience when wind scales or hyperbolic dividers (see, for instance, Lichtblau[6] and Spilhaus[7]) are employed.

Water Vapor

As a result of Byers'[5] proposal it has become prevalent to represent water vapor by isentropic condensation-pressure, the equivalent on charts bearing isotherms being isentropic condensation-temperature. Rate of transfer by mixing depends, however, on the gradient of concentration, so it is believed advisable to adhere to Rossby's[8] initial use of specific humidity lines, or q-lines. Most of the advantages of representing isentropic condensation-temperature directly may be maintained by labeling the q-lines with the appropriate values of the condensation-temperature also, or by labeling the isotherms with the appropriate saturation specific humidity also. It is, however, quite adequate simply to have at hand a table of one or both of these

* This is the interval at which surface observations are made. Furthermore it is the most convenient interval for the use of wind scales; on isentropic charts for the United States the average wind travel in six hours, the average distance between streamlines spaced by 4 megergs g, the average travel of the shear-stability ratio vector in a quarter hour, and the average distance between 10°-isotherms are all of about the same magnitude.



Isentropic chart. At each radiosonde station (black circle) the temperature (°C) is entered on the right, the last two figures of the acceleration potential in megergs g^{-1} on the left, the specific humidity in parts per mille below. An arrow originating from one of these stations is the distance traveled in a quarter hour at the velocity of the shear-stability ratio vector, a broken shaft indicating that it is based on the 0400 GMT pilot balloon observation and a full shaft for 1000 GMT. A plain line directed toward any station circle is the distance traveled in six hours at the velocity of the wind. Full curves are isotherms. Curves represented by arrows are isopleths of acceleration potential (streamlines), labeled in megergs g^{-1}. Broken fine curves are *q*-lines. Saturation areas are stippled (conformal conic projection, scale 1:32 million at latitudes 30° and 60°).

quantities for the particular isentropic surface (see inset table on accompanying illustration).

In addition to aerological data further information for isentropic analysis is afforded by surface observations, particularly hydrometeors. Consequently the analyst needs to have before him not only a plotted isentropic chart, but also the plotted surface chart.

Order of Analysis

An isentropic analysis consists of drawing the fields of temperature, of motion, and of saturation and specific humidity—as well as the visualization of the meteorological processes involved, which are not directly represented. The information available for drawing any one of these three fields is, first, the observed or computed values of the quantity in question and, second, the fields of the other two and of the hydrometeors. Thus it is necessary to proceed by successive approximations. The order of procedure is, however, not arbitrary; it is quite definitely prescribed by considerations of the relative independence of the three fields.

Of primary significance is obviously the configuration of the isentrope, for the field of any quantity on a surface not located is of no practical importance. The dependence of the other fields on the configuration and on the temperature distribution has already been discussed. Once the first approximation to the temperature field has been drawn the pilot balloon observations at intervening stations can be entered and the field of motion drawn. The last to be drawn is the moisture field, for which there are fewest aerological data. The indicated procedure is therefore as follows:

(a) An isentropic chart is plotted. At each radiosonde station are entered pressure, temperature, isentropic acceleration potential, specific humidity and saturation specific humidity. When available from the same or a nearby station the wind and shear-stability vector also are entered.

(b) Isotherms are drawn. These are based primarily on the plotted temperatures and shear-stability ratio vectors, but qualitative use is made of the other information.

(c) Winds from intervening pilot balloon stations are entered. The elevation employed is a fixed conversion from temperature by means of the pressure-height relation of the standard atmosphere (see inset table on accompanying illustration).

(d) Streamlines are drawn, using primarily the values of the acceleration potential and the wind observations.

(e) Saturation areas are outlined and q-lines drawn. It is then nearly always found necessary to modify some details of the first approximation, especially of the isotherms.

An example of charts obtained in this manner is shown in the illustration.*

Application of Shear-Stability Ratio Vectors

In the United States the late evening and early morning pilot balloon ascents are six hours apart, and the radiosonde ascents are made in about the middle of the interval. Shear-stability ratio vectors are computed by use of both sets of wind data, so that in the illustration there are two vectors at many of the stations. Since neither set is computed from simultaneous observations of shear and of stability, it is not surprising to find some marked differences. But there is sufficient correlation to demonstrate that the vectors, even from the non-simultaneous observations available, have a real significance. Thus they add greatly to the information which can be used in isentropic analysis. Each reliable vector gives twice as much information about the configuration of the isentrope as does the elevation of the isentrope at a radiosonde station.

It is apparent, however, that this tool cannot be utilized fully without observing stability and shear simultaneously. Spilhaus[1] has already suggested an appropriate procedure for accomplishing this, namely, to observe the radiosonde balloon itself with a theodolite.** This would ensure exact simultaneity and would have the great advantage that the rate of ascent need not be assumed, the geopotential at any instant being known from the radiosonde.

It is important to note also that the data from radiosondes and pilot balloons as transmitted daily are not as complete as desirable for computing the shear-stability ratio vectors.[1] The authors therefore recommend

* There is necessarily some confusion in the illustration due to the representation of the data as well as all isopleths on one chart. In practice this is avoided by representing (a), (b) and (c) on a base map, and by placing (d) and (e) each on a separate transparent overlay.

** This suggestion was carried out by the United States Weather Bureau at several of their stations for a trial period during November and December, 1940.

strongly, first, that the winds be observed simultaneously with each radiosonde and, second, that the vectors for the chosen isentropic surfaces be computed at the radiosonde stations.

Warming and Cooling

In discussing weather situations on isentropic charts some consistent terminology is necessary. Thus certain graphic words have come into use, such as *dome* or *ridge* and *trough* (which are determined practically by isotherms or isobars), *cyclone* and *anticyclone*, and *moist* and *dry*. There is need also for terms to describe adiabatic changes, which might be stated loosely with such words as "lifting" or "rising," or precisely in terms of change of pressure or temperature. The last is most convenient, especially on charts bearing isotherms, and gives the simple words *cooling* and *warming*. Furthermore these need to be resolved into two components. The rate of change of temperature of an air parcel moving isentropically may be written

$$\frac{dT}{dt} = \left(\frac{dT}{dt}\right)_{s,x,y} + \left[u\left(\frac{dT}{dx}\right)_{s,y,t} + v\left(\frac{dT}{dy}\right)_{s,x,t}\right], \quad (9)$$

u and v being velocity components parallel to x- and y-axis, respectively. It is proposed to call the first term *local warming*, and the second *convective warming*.

Differentiation between these two is essential. When rapidly moving air ascends a relatively stationary ridge the first term is small, giving convective cooling which may lead to the type of precipitation associated with warm fronts. When a rapidly moving ridge advances under relatively stationary air the second term is small, giving local cooling which may lead to the type of precipitation associated with cold fronts.

The convective warming of air moving isentropically can be quantitatively estimated directly on the isentropic chart. If, as in the chart on accompaning illustration, observed winds are represented vectorially as the distance traveled in six hours, the convective warming in six hours is the temperature increase along the vector (provided the fields of temperature and wind are constant along the vector). In the absence of observed winds, if geostrophic flow is assumed, convective warm-

ing can be evaluated from the isopleths of acceleration potential.*

Upper-Air Analysis in Moist Air

Conservatism

In choosing a surface for upper-air analysis perhaps the first desirable feature is conservatism, by which is meant that the value of some conservative property be constant on the surface. Then, within the limitations of the conservatism of the particular property, it is a material surface, so that any parcel on the surface at one time is somewhere on the same surface at any other time. This was the consideration which led to the choice of a surface of constant potential temperature, in conjunction with specific humidity as a second conservative property, for studying flow patterns.

It is paradoxical that, while in isentropic analysis one is interested specifically in the fluid's variable composition, heretofore no attention** has been paid to the effect of variable moisture content on the physical properties of air.

Potential temperature is defined as the temperature a substance would have if changed adiabatically from its actual state to a standard pressure. Only when so defined is potential temperature a truly conservative property during adiabatic processes. For a perfect gas† having constant specific heat the relation between temperature, pressure, standard pressure p_0 and potential temperature is given by Poisson's equation

$$\frac{T}{\theta} = \left(\frac{p}{p_0}\right)^{R/mc_p} \tag{10}$$

where, as throughout this paper, m and c_p are the values appropriate for the particular gas mixture in question, not necessarily those for dry air.

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* Note added April, 1941: Now that twice daily radiosonde ascents are made in the United States, the observed twelve-hour warming on the isentrope may often give an approximation to the instantaneous rate of local warming. When this is so, the total warming may be obtained, which is obviously of great significance. It indicates, for example, the rate at which the air is approaching saturation.

** With the exception of a remark by Montgomery.[2]

† For brevity throughout this paper the term *perfect gas* is used for a substance whose equation of state may be written as in (12), where R is a universal constant and m is the mean molecular weight of the substance.

Potential density is defined as the density a substance would have if changed adiabatically from its actual state to a standard pressure. Designating it by ρ_s, the relation corresponding to (10) is

$$\frac{\rho}{\rho_s} = \left(\frac{p}{p_0}\right)^{c_v/c_p}. \tag{11}$$

Let *virtual potential temperature* be the virtual temperature* a substance would have if changed adiabatically from its actual state to a standard pressure. This serves as a convenient measure of potential density, just as virtual temperature and pressure describe density. For a perfect gas, designating the mean molecular weight of dry air by m_d, virtual temperature by T_v and virtual potential temperature by θ_v, since

$$p = \frac{R}{m}\rho T \tag{12}$$

and

$$p = \frac{R}{m_d}\rho T_v, \tag{13}$$

it follows that

$$p_0 = \frac{R}{m}\rho_s \theta = \frac{R}{m_d}\rho_s \theta_v. \tag{14}$$

Hence

$$\frac{\theta}{\theta_v} = \frac{m}{m_d} \tag{15}$$

and, if specific heat is constant,

$$\frac{T_v}{\theta_v} = \frac{T}{\theta} = \left(\frac{p}{p_0}\right)^{R/mc_p}. \tag{16}$$

Potential temperature and virtual potential temperature are both conservative during adiabatic processes, so each defines surfaces which from this point of view are equally suitable for upper-air analysis. In a surface described by the constancy of one of these the other is constant if the medium is of uniform composition, otherwise it is variable.

* The *virtual temperature* of a substance is the temperature of matter of standard composition at the same pressure and density. In meteorology dry air is adopted as the standard matter. Furthermore one may adopt dry air, assumed to be a perfect gas, as the standard matter regardless of the nature of the actual substance, obtaining (13) above as a completely general relation.

Entropy is a third conservative thermodynamic property. But, while classical thermodynamics enables one to compute the change in specific entropy from a standard state to any other state for a given substance, it gives no means of relating the entropies of various samples having different compositions and hence no means of defining an isentrope in the moist atmosphere. Upper-air analysis on an isentrope is therefore feasible only when the presence of water may be neglected.

Hydrostatic Equilibrium

A surface suitable for upper-air analysis should have the second desirable feature of hydrostatic equilibrium for adiabatic displacement. If a parcel is displaced to all possible positions where it is in hydrostatic equilibrium in a stable fluid, a surface is described. This surface then passes through the parts of the fluid with which the parcel is most likely to come in contact—of obvious importance in the consideration of mixing processes. Since adiabatic compressibility depends on composition the surface of hydrostatic equilibrium for one parcel does not in general coincide with the surface for another parcel even though the latter parcel lies in the former surface. While there is thus no complete solution for this desideratum, a high degree of approximation to it may be attained.

It is of interest first to find the relation between the potential temperature θ' of an air parcel and the potential temperature θ of the environment where it is in hydrostatic equilibrium. If neither contains condensed water, for the environment

$$\theta = T\left(\frac{p}{p_0}\right)^{-R/mc_p} = \frac{m}{R}\frac{p}{\rho}\left(\frac{p}{p_0}\right)^{-R/mc_p}.$$

and for the parcel

$$\theta' = T'\left(\frac{p'}{p_0}\right)^{-R/m'c_{p'}} = \frac{m'}{R}\frac{p'}{\rho'}\left(\frac{p'}{p_0}\right)^{-R/m'c_{p'}}.$$

The condition of hydrostatic equilibrium stipulates that $p = p'$ and $\rho = \rho'$, so

$$\frac{\theta'}{\theta} = \frac{m'}{m}\left(\frac{p}{p_0}\right)^{[(R/mc_p)-(R/m'c_{p'})]}. \tag{17}$$

The two factors on the right (if $p < p_0$) are both greater than unity if the parcel is dryer than the environment, both less than unity if it is more moist. In the first

case the potential temperature of the parcel is greater than that of the environment; in the second, less.

The second factor depends on pressure and specific humidity. In the atmosphere (so long as the "dry" composition is constant) its maximum possible deviation from unity is 0.1 per cent and occurs at about 500 mb.

The ratio of the mean molecular weights can, however, vary considerably. For an extreme difference in specific humidity of 30 ‰ it differs from unity by 1.8 per cent, corresponding to a difference in potential temperature of about 5°C.

Such a value is of definite significance, and shows that severe restrictions are imposed on the use of surfaces of constant potential temperature in upper-air analysis. For instance, the range of specific humidity observed on January 9, at $\theta = 298°$ was 18 ‰. If parcels from the two extreme regions were brought adiabatically to hydrostatic equilibrium at the same vertical, the more moist one would lie considerably above the dryer one. In order for them to come into juxtaposition the moister one should be picked from a surface lower by more than 3°C, even if specific humidity does not increase downward from $\theta = 298°$. If the lapse rate in the region of the moist air is half the dry adiabatic, the parcel should be picked from a level more than 600 meters below.

However, substitution of virtual potential temperature in (17) by means of (14) gives

$$\frac{\theta_v'}{\theta_v} = \left(\frac{p}{p_0}\right)^{[(R/mc_p)-(R/m'c_p')]} . \qquad (18)$$

The quantity remaining on the right was found to differ from unity by less than 0.1 per cent. Hence two air parcels of the same virtual potential temperature and containing no liquid water can come nearly into hydrostatic equilibrium.*

The feature concerning hydrostatic equilibrium for upper-air analysis is thus practically fulfilled by a surface of constant virtual potential temperature. A surface of constant potential temperature is not suitable.

Multiple Isopleths

The third feature desirable in a surface for upper-air

* Substitution of potential virtual temperatures (see above, Eq. 19) in (18) gives unity as their ratio. This, however, has no significance, because potential virtual temperature is non-conservative to exactly the same small extent by which the right side of (18) differs from unity.

analysis is that a single family of isopleths on the surface represent as much related information as possible. For example, on an isentrope in a medium of uniform composition an isotherm is an isobar and is an isopycnal. In the moist atmosphere, except in regions containing condensed water, pressure and density are nearly constant along an isotherm of virtual temperature on a surface of constant virtual potential temperature. From (16) it is seen that T_v/θ_v is determined by pressure within 0.1 per cent, so that pressure is determined by T_v/θ_v within 0.4 per cent. Pressure and virtual temperature, of course, determine density exactly.

While pressure is determined within 0.4 per cent by T/θ, pressure and temperature determine density with a maximum error of 1.8 per cent. Also in this respect, therefore, a surface of constant potential temperature is not suitable for upper-air analysis.

Let the *potential virtual temperature* of a substance be the potential temperature of matter of standard composition at the same pressure and density. Designating it by ${}_v\theta$, if the standard matter is dry air and is assumed to be a perfect gas having constant specific heat,

$$\frac{T_v}{{}_v\theta} = \left(\frac{p}{p_0}\right)^{R/(mc_p)_d}. \tag{19}$$

By comparing this with (16) it is seen that, under the restrictions stated, potential virtual temperature and virtual potential temperature differ by less than 0.1 per cent.

In contrast to the approximate result obtained for a surface of constant virtual potential temperature, on one of constant potential virtual temperature, in any medium, pressure and density are constant along an isotherm of virtual temperature.

On the other hand a surface of constant virtual potential temperature in a medium composed of a continuously varying mixture of two substances has the property that a line of constant composition is an isopleth of potential temperature and of entropy.

In a region of saturated air containing no condensed water a single family of such isopleths on a thermodynamically defined surface can of course represent all the variables mentioned. For instance, an isotherm of virtual temperature on a surface of constant potential virtual temperature is an isopleth not only of pressure and density, but also of specific humidity, temperature,

of potential and virtual potential temperatures, and of entropy.

Acceleration Potential

The fourth feature desirable for upper-air analysis is that the surface has an acceleration potential. It will be found that a surface of constant potential virtual temperature satisfies this condition.

For any surface designated by A it is seen from a consideration of the pressure change along its intersection with the z,x-plane that

$$\left(\frac{dp}{dx}\right)_{A,y,t} = \frac{\partial p}{\partial x} + \frac{\partial p}{\partial z}\left(\frac{dz}{dx}\right)_{A,y,t}. \quad (20)$$

Combining this with the hydrostatic equation,

$$\frac{d\Phi}{dz} = -\alpha\frac{\partial p}{\partial z}, \quad (21)$$

gives[2]

$$-\alpha\frac{\partial p}{\partial x} = -\left(\frac{d\Phi}{dx}\right)_{A,y,t} - \alpha\left(\frac{dp}{dx}\right)_{A,y,t}. \quad (22)$$

This, with the corresponding y-component, is the force per unit mass associated with the horizontal pressure gradient. For certain specific surfaces the two terms on the right of this perfectly general expression reduce to the variation of a single quantity, the negative acceleration potential.

Elimination of virtual temperature from (13) and (19) gives

$$\alpha = \frac{R}{m_d}\frac{{}_v\theta}{p}\left(\frac{p}{p_0}\right)^{R/(mc_p)_d}, \quad (23)$$

so

$$\alpha\frac{dp}{dx} = c_{pd}\,{}_v\theta\frac{d}{dx}\left(\frac{p}{p_0}\right)^{R/(mc_p)_d}. \quad (24)$$

Hence

$$\alpha\left(\frac{dp}{dx}\right)_{v\theta} = c_{pd}\left\{\frac{d}{dx}\left[{}_v\theta\left(\frac{p}{p_0}\right)^{R/(mc_p)_d}\right]\right\}_{v\theta} = c_{pd}\left(\frac{dT_v}{dx}\right)_{v\theta}, \quad (25)$$

and from (22)

$$-\alpha\frac{\partial p}{\partial x} = -\left(\frac{d(\Phi + c_{pd}T_v)}{dx}\right)_{v\theta,y,t}. \quad (26)$$

with a similar expression for the y-component.

Thus for a surface of constant potential virtual temperature in any medium, provided the standard matter is a perfect gas having constant specific heat, there is an exact acceleration potential,

$$\Upsilon = \Phi + c_{pd} T_v. \tag{27}$$

There is none for a surface of constant potential temperature except under special conditions.

Shear-Stability Ratio Vector

The fifth feature desirable in a surface for upper-air analysis is that, for geostrophic flow, the configuration of the surface be given by some simple function of velocity and density distributions along the vertical.

The Bjerknes[9] circulation theorem for frictionless flow states that, for a closed path having circulation relative to the earth C_r and projection on the equatorial plane F,

$$\frac{dC_r}{dt} + 2\omega \frac{dF}{dt} + \oint \alpha \, dp = 0. \tag{28}$$

where ω is the angular velocity of the earth. The first term vanishes for geostrophic flow. By choosing a small circuit in a plane normal to the y-axis and composed of two verticals and two isobars the other two terms, on dividing by the distance between verticals and by the pressure difference of the isobars, become

$$\left(\frac{dv}{dp}\right)_{x,y,t} + \frac{1}{f}\left(\frac{d\alpha}{dx}\right)_{p,y,t} = 0. \tag{29}$$

From (23)

$$\left(\frac{d\alpha}{dx}\right)_p = \frac{\alpha}{{}_v\theta}\left(\frac{d_v\theta}{dx}\right)_p \tag{30}$$

and, in the same manner as (20),

$$0 = \left(\frac{d_v\theta}{dx}\right)_{p,y,t} + \left(\frac{d_v\theta}{dp}\right)_{x,y,t}\left(\frac{dp}{dx}\right)_{v\theta,y,t}. \tag{31}$$

Solving (25), (29), (30), (31) yields

$$\left(\frac{dv}{d \ln {}_v\theta}\right)_{x,y,t} = c_{pd}\left(\frac{dT_v}{dx}\right)_{v\theta,y,t}. \tag{32}$$

A similar equation results for the other component.

Stability may be defined as the ratio of the negative vertical acceleration of a fluid parcel to its geopotential

displacement from equilibrium. From (19) it may consequently be written

$$E = \frac{1}{{}_v\theta}\left[\frac{\partial\,{}_v\theta}{\partial z} - \left(\frac{\mathrm{d}\,{}_v\theta}{\mathrm{d}z}\right)_{\text{parcel}}\right]. \tag{33}$$

If no condensed water is present in the air, potential virtual temperature differs only very slightly from virtual potential temperature, a conservative property, so the second term is commonly negligible. Hence

$$\left(\frac{\mathrm{d}v}{\mathrm{d}\,\ln\,{}_v\theta}\right)_{x,\,y,\,t} = \frac{\partial v}{\partial z}\Big/\frac{1}{{}_v\theta}\,\frac{\partial\,{}_v\theta}{\partial z} \sim \frac{1}{E}\,\frac{\partial v}{\partial z}, \tag{34}$$

the y-component of the shear-stability ratio vector.

Therefore on a surface of constant potential virtual temperature in any fluid, provided the flow is geostrophic and the standard matter is a perfect gas having constant specific heat, the gradient of virtual temperature is related simply and exactly to the vector on the left side of the equations represented by (32). The latter is a close approximation to the shear-stability ratio vector when no condensed water is present.

Analysis in Saturated Regions

In regions where the air is composed partly of an unknown amount of water in droplets or ice particles its thermodynamic properties are essentially non-conservative due to the exchange of water with other layers. Isentropic analysis loses much of its significance in these regions, and therefore Byers[5] omits isopleths from saturated areas on his isentropic charts. It is, however, advantageous to continue an upper-air analysis through saturated regions. Since wind measurements are generally lacking, construction of streamlines by use of the acceleration potential is especially important.

Potential virtual temperature is affected only slightly by the presence of liquid or solid water, and can be computed to a close approximation from pressure, temperature and humidity without regard to condensed water. The analysis of virtual temperature and acceleration potential on a surface of constant potential virtual temperature may therefore be carried out in a saturated region just as elsewhere. The isopleths of specific humidity (ratio of density of water vapor to total density) are determined by the isotherms of virtual temperature to the same approximation.

It is, however, not possible to compute the virtual temperature or potential temperature of air composed partly of an unknown amount of condensed water.

Conclusions

To summarize, it has been seen that four important desiderata for upper-air analysis are satisfied exactly by either a surface of constant virtual potential temperature (constant potential density) or by one of constant potential virtual temperature. These two surfaces agree with each other, and satisfy a fifth desideratum, provided no condensed water is present, within an error amounting at most to 0.1 per cent in terms of temperature.

From these considerations it appears that either a surface of constant virtual potential temperature or one of constant potential virtual temperature is the most suitable for upper-air analysis. The choice is dictated by the fact that of these two only the surface of constant potential virtual temperature lends itself to practical use in regions where water is present in liquid or solid form. Furthermore it is more easily calculated than virtual potential temperature. Potential virtual temperature may be obtained from virtual temperature and pressure in exactly the same fashion as the potential temperature of dry air is computed from temperature and pressure. Virtual temperatures are used in any event for the computation of geopotential and therefore no additional labor is involved.

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PLATE 14

FIG. 1. *Metula fusiformis* Cl. and Ag. Holotype, × 1½.
.. 2. *Howellia mirabilis* Cl. and Ag. Holotype, nat. size.
.. 3. *Latirus mcmurrayi* Cl. and Ag. Holotype, × 1½.
.. 4. *Metula agassizi* Cl. and Ag. Holotype, × 1½.

NOTES AND DESCRIPTIONS OF NEW DEEP-WATER MOLLUSCA OBTAINED BY THE HARVARD-HAVANA EXPEDITION OFF THE COAST OF CUBA. IV[1]

BY W. J. CLENCH AND C. G. AGUAYO

The present paper continues the reports upon the material obtained by the *Atlantis* during the two winter cruises of 1938 and 1939.

Howellia[2] New Genus

Shell extended, fusiform and possesing a somewhat flaring lip. Canal short and fairly broad, merging into the base of the aperture.

We place the genus *Howellia* provisionally in the family Fasciolariidae. A single specimen only was collected, with the soft parts decayed to such an extent that the shell was cleaned and preserved dry during the trip.

Genotype: HOWELLIA MIRABILIS

Howellia mirabilis new species

(PLATE 14, FIG. 2)

Description. – Shell extended, rather solid, shining, imperforate and strongly sculptured. Whorls 10, convex and regularly increasing in size. Color cream, tinged dully with brownish red. Interior of aperture reddish brown and extending on the columella and outside and the canal. Lip margined by a white band within. Columella straight. Outer lip simple, rather sharp and slightly flaring. In profile view, the lip is trongly sinuous. Inner lip but faintly glazed. Aperture rather long and narrow. Sculpture of strong sinuous axial costae crossed on the early whorls by very fine incised lines which disappear on the later whorls. The axial costae produce a finely crenulated suture.

(1) Contribution no 289, Woods Hole Oceanographic Institution.
(2) Named for Dr. L. Howell y Rivero, a member of the *Atlantis* Expedition.

Length	*Width*	*Aperture*	
93	28	44.5 × 10 mm.	Holotype

Holotype. – Mus. Comp. Zool. No. 135291, *Atlantis* station No. 3483 (N. Lat. 23° 12′; W. Long. 81° 23′) off Matanzas, Matanzas Prov., Cuba, Dec. 9, 1939 in 285 fathoms.

Latirus (Hemipolygona) mcmurrayi new species

(Plate 14, fig. 3)

Description. – Shell solid and strong, openly umbilicate and somewhat extended. Color probably a yellowish brown or yellowish gray. Whorls 9, regularly increasing in size and very moderately convex. Spire extended and acute, forming an angle of 42°. Palatal lip simple with a series of low costae and below them a few pustulations well within the aperture. Parietal all thickened. Columella short but continued into a backwardly recurved canal. Suture moderately indented. Umbilical region margined by a wide flaring base. Umbilicus proper rather wide with 2 whorls visible within. Sculpture of strong and rother bold axial nodules numbering 6 on the body whorl. Fine sculpture consisting of fairly strong growth lines crossed by numerous spiral threads, both visible to the unaided eye. Nuclear whorl corroded but apparently with small nodules.

Length	*Width*	*Aperture* (without canal)	
51.5	22.7	13 × 8 mm.	Holotype

Holotype. – Mus. Comp. Zool. No. 135285, *Atlantis* station 3482 (N. Lat. 23° 09′; W. Long. 81° 27′ 30″) off Matanzas, Matanzas Prov., Cuba, May 11, 1939, in 190 fathoms.

Remarks. – A single and recently dead specimen was obtained.

In relationship, it is nearest to *L. maderensis* Watson, from off Ponta de São Lourenco, Madeira Islands (50 fathoms). It differs mainly in being proportionately longer and having two more whorls and especially in lacking the very strong spiral costae of the latter species. The canal as well is produced vertically and not strongly recurved backwardly as in *L. mcmurrayi*.

Watson proposed the genus *Chasca*, [1] with *maderensis* as its only species, however, the name being preoccupied, was changed by Rovereto to *Hemipolygona* (1899). This name appears to have little above sectional value, as both of these species represent only an extreme in the development of the umbilical flaring, a character

(1) Proc. Zool. Soc. London, 1873, p. 361, pl. 36, fig. 30.

held in common with most other species in the genus *Latirus*. We retain *Hemipolygona* only to indicate the relationships of these two species.

We take pleasure in naming this new form after Captain F. S. McMurray of the *Atlantis*.

Metula fusiformis new species

(PLATE 14, FIG. 1)

Description. – Shell solid, dull, elongate and rather coarsely sculptured. Whorls 9, strongly convex and regularly increasing in size. Nuclear whorls (2) with minute axial ridges or costae. Color a dull straw yellow. Aperture suboval, and extended below into a short canal. Spire produced and formed at an angle of 37°. Palatal lip thickened and margined within by a series of fine teeth. Parietal wall somewhat thickened and glazed. Interior of aperture porcelain white and shining. Columella arched above and obtusely angled at the beginning of the canal. Suture indented. Sculpture of coarse axial costae (13 on body whorl) which are crossed by numerous and rather coarse spiral threads. Canal somewhat lengthened and recurved backwardly when viewed in frontal position.

Length	*Width*	*Aperture*	
49	15.8	25.2 × 7 mm.	Holotype

Holotype. – Mus. Comp. Zool. No. 135290, *Atlantis* Station 3344 (N. Lat. 21° 38′; W. Long. 80° 12′) off Cienfuegos, Santa Clara Prov., Cuba, April 8, 1939, in 1440 fathoms.

Remarks. – A single specimen collected. Similar in general outline to *M. aggassizi* but differing considerably in the scupture and somewhat more lengthened canal.

Metula agassizi new species

(PLATE 14, FIG. 4)

Description. – Shell solid, dull, elongate and finely sculptured. Whorls 8, rather strongly convex and regularly increasing in size. Nuclear whorls (2) smooth and glass-like. Color white under a thin, pale straw periostracum. Aperture suboval, extended below into a short canal. Spire produced forming an angle of 37°. Palatal lip thickened and sculptured at the thickened area within with a series of very fine teeth. Parietal wall heavily glazed. Interior of aperture porcelain white and shining. Columella arched above and obtusely angled at the base of the aperture at the beginning of the

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FINE STRUCTURE OF THE EDGE OF THE GULF STREAM

Athelstan F. Spilhaus

(Abstract)

(Contribution No. 290 of the Woods Hole Oceanographic Institution)

Purpose--The purpose of the following investigation is to obtain a detailed description of conditions in a region of great lateral shear and to attempt to represent synchronous conditions on surfaces in a lateral plane.

Previous indications--Two sections through the edge of the Gulf Stream made in 1939, namely, (a) with the bathythermograph (July) and (b) with the bathythermograph and pressure-operated sea-sampler (August), had shown, from (a), a complex temperature-structure suggesting the presence of eddies and, from (b), that the complex temperature-structure was the result of lateral juxtaposition of different water-types probably by eddying motion [see 4 of "References" at end of paper].

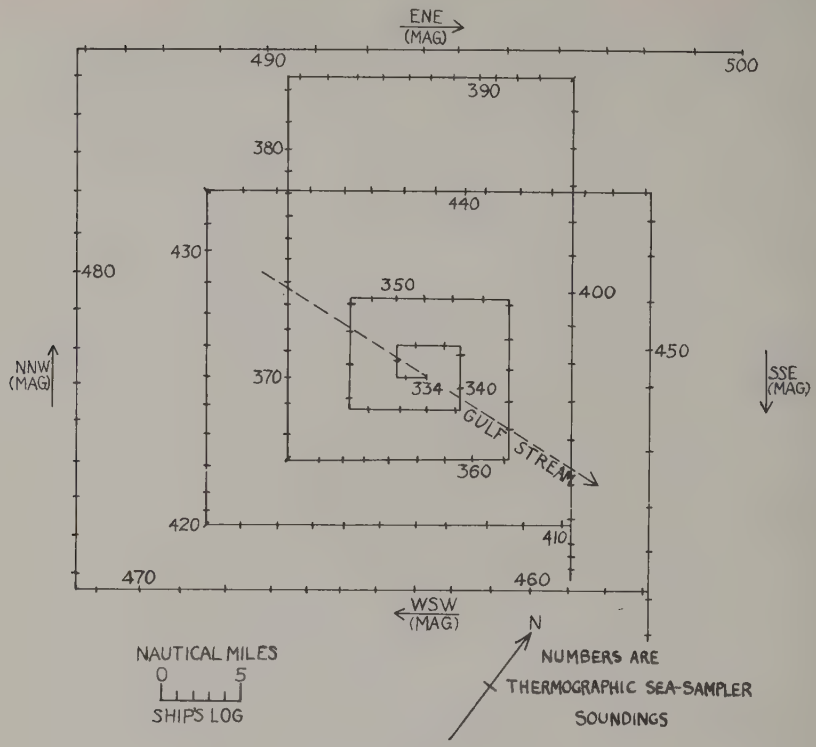

Fig. 1--Ship's run

Choice of region--The neighborhood of the Gulf Stream is chosen because eddies will be found where there is great lateral shear. To identify these eddies most easily the region was selected where horizontal temperature-gradients are greatest. The "edge" of the Stream as defined in this way (by the region of greatest horizontal temperature-gradient) is well within the boundary defined by the velocity. (Observations by Church in 1937 [1] of surface-temperatures give a far narrower "stream" than that, for instance, Iselin in 1936 [2] defined on the basis of where the velocity falls to ten cm per second.)

The region was located on the outward course by making a section by the regular hydrographic technique down to about 1,000 decibars. The edge of the Stream was identified and the vessel taken well into the Stream. The course was then retraced using the bathythermograph continuously and the starting point for the detailed investigation was thus selected (about latitude 37° 40' north and longitude 69° 10' west). Starting at this point, a run was made by log and compass as in Figure 1.

Instrument--During the whole run, soundings were made continually with a new instrument, the thermographic sea-sampler. This instrument is a combination of the bathythermograph and pressure-operated sea-sampler [4] using a single pressure-element. It is used just as is the bathythermograph, while under weigh and in a single sounding provides a recorded trace of temperature against pressure and also six samples of sea-water at different predetermined pressures (I, Fig. 2). The maximum pressure for this instrument was 150 decibars; in order to reach this depth without exceeding it by much and thereby incurring the possibility of damaging the pressure-element, it was necessary to obtain an idea of the "wire-out: depth-reached" relationship for different speeds of the vessel. This was greatly facilitated by the barochronograph (II, Fig. 2) used for the purpose on an earlier short cruise. (This latter instrument, although in crude form, has been used with nets and with the Hardy plankton-recorder with interesting and useful results.)

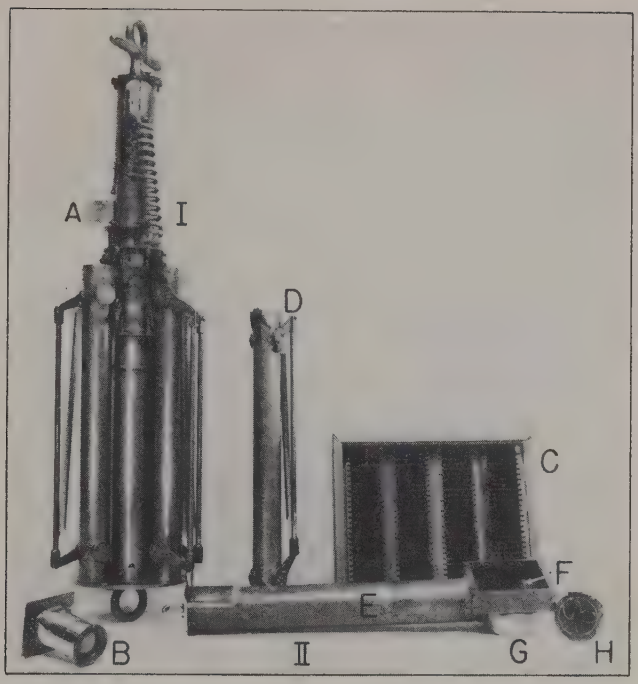

Fig. 2--(I) Thermographic sea-sampler (combined bathythermograph and sea-sampler)
[A = slide with temperature-pressure trace; B = viewer--slide A is viewed superimposed on calibration-grid, thus permitting immediate reading off of pressure-temperature data; C = box of temperature-pressure record slides; D = sample-bottle, removed from instrument, cocks closed]
(II) Barochronograph
[Pressure-element in E moves pen radially outward on octagonal slide in F, rotated by clock G; slide H shows original barochronograph-record for four soundings at different speeds of vessel]

Collection of data--While the Atlantis was executing the run which occupied three days (from August 23 to 26, 1940) up to the occurrence of a severe storm (at sounding No. 500), soundings were made on an average of one every 22-1/2 minutes, that is, every two miles corresponding to an average speed throughout the run of 5-1/2 knots.

Each sounding provided (1) a record of temperature against pressure down to 150 decibars and (2) samples of water from the surface and six other evenly spaced levels down to 150 decibars.

The samples were divided into two parts, one for oxygen-determination (carried out on board concurrently), the other stored (in special small bottles) for subsequent chlorinity-determinations.

In all, 230 thermographic sea-sampler soundings were made providing 1,610 oxygen-values and the same number of chlorinities. Of these, 200 soundings with 1,400 oxygen- and chlorinity-values were those taken in the water under detailed investigation in a period of 3-1/2 days.

Treatment of data--Thus for the surface and six other levels, pressure, temperature, chlorinity, and oxygen were known and σ_t was determined so that for a given value of σ_t, pressure was scaled off a plot of σ_t versus pressure; with this pressure, temperature was read off the original record of the instrument and the value of oxygen scaled off a plot of the seven sample-points. The temperature- and oxygen-distribution on the σ_t-surface could then be represented and the configuration of the surface, in terms of pressure, drawn. [For other analyses of conditions on σ_t-surfaces see, for example, Montgomery 1938.]

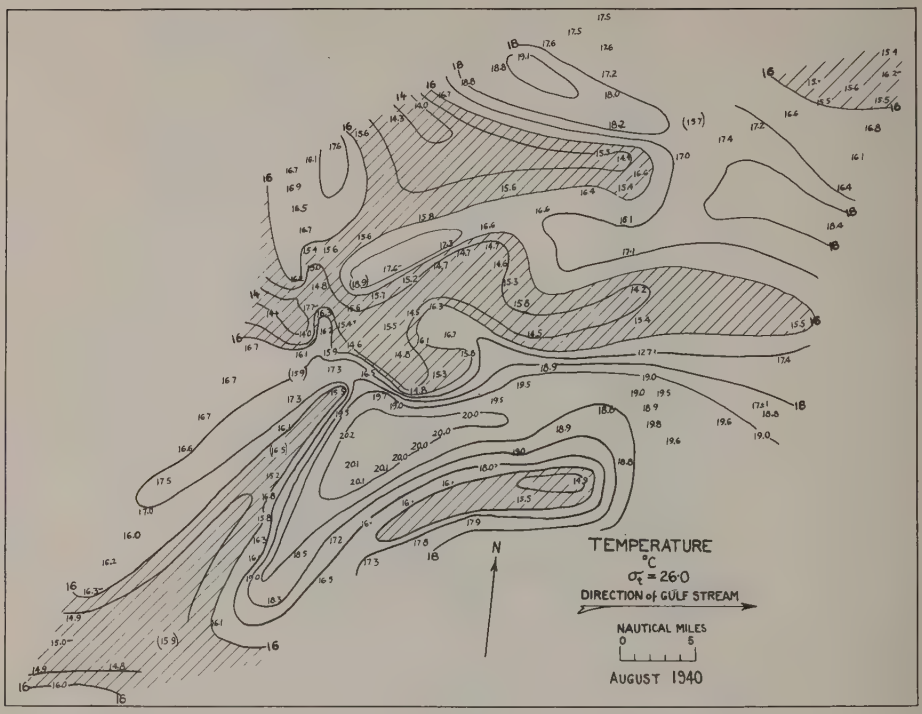

Fig. 3--Temperature-distribution on surface σ_t = 26.0

Representation of conditions on σ_t-surface--Although the new rapid-measuring hydrographic technique provides a means, with one vessel, of approximating simultaneous collection of the data, it is desirable to reduce the position of the soundings to that which would have obtained if they had been taken exactly simultaneously. The relative positions of the water-parcels encountered by the instrument were computed as they were at the time of the start of the run.

This reduction was carried out under the following assumptions:

(i) All flow parallel to the observed mean direction of the Stream.
(ii) Surface velocity-gradient constant and equal to the mean value for the region obtained by computation of velocities (relative to the 1,000-decibar surface) from the deep hydrographic section taken on the outward course. The value of the surface horizontal shear found in this manner = 10^{-5} sec^{-1}.
(iii) Velocity-difference between sea-surface and σ_t-surface analyzed is constant and equal to the mean value obtained by computation as in (ii). The velocity at σ_t = 26.0 was found to be 14 cm/sec less than the sea surface-velocity in the mean.

The procedure of reduction of the position of the water-parcels to time of start of run (sounding No. 334) is then:

(i) Mean sea-surface drift is eliminated by making run by log and compass.
(ii) Ship's track relative to axes moving with surface-water at point of start of run is computed using computed mean sea-surface shear.
(iii) Water parcels encountered on ship's track in σ_t-surface are reduced to positions relative to sounding No. 334 by computed velocity-distribution in surface and elapsed time between the particular sounding and sounding No. 334.

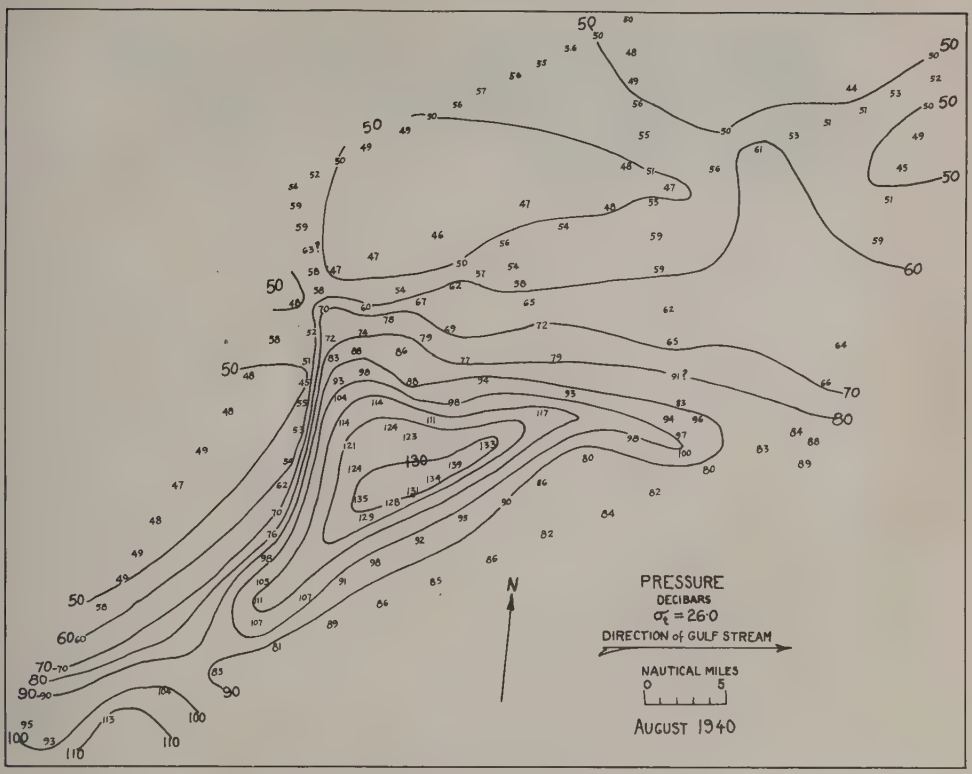

Fig. 4--Pressure-distribution on surface σ_t = 26.0

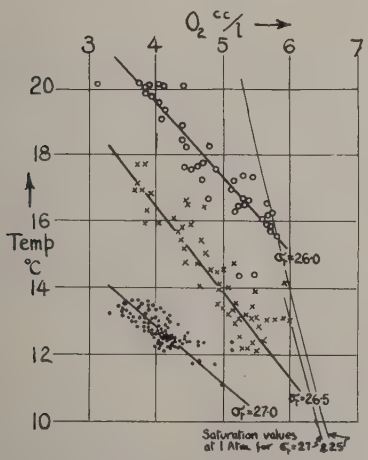

Fig. 5--Oxygen-temperature correlation on σ_t-surfaces

Reduced grid--The result of this reduction is a skewing distortion of the run-grid. Widely different values of shear and direction of Stream give greater or lesser distortion, but the main features of the grid remain little changed.

Analysis on a σ_t-surface--The distribution of temperature, oxygen, and pressure on various surfaces of constant σ_t could then be drawn. For the purpose of studying the flow, temperature is the most satisfactory indicator on the σ_t-surface. (Chlorinity or salinity might equally well be used as each is a single valued function of temperature on a σ_t-surface. Here it is preferred to use chlorinity solely to determine density and thereafter, as its distribution is known in detail, to use temperature as the indicator.)

Oxygen-distribution on the σ_t-surface gives an independent indicator of the flow provided that the surface is not found at shallow depths where the oxygen is non-conservative.

The pressure-contours serve to locate the σ_t-surface but are non-conservative.

The temperature- and pressure-distribution on the surface σ_t = 26.0 are shown in Figures 3 and 4.

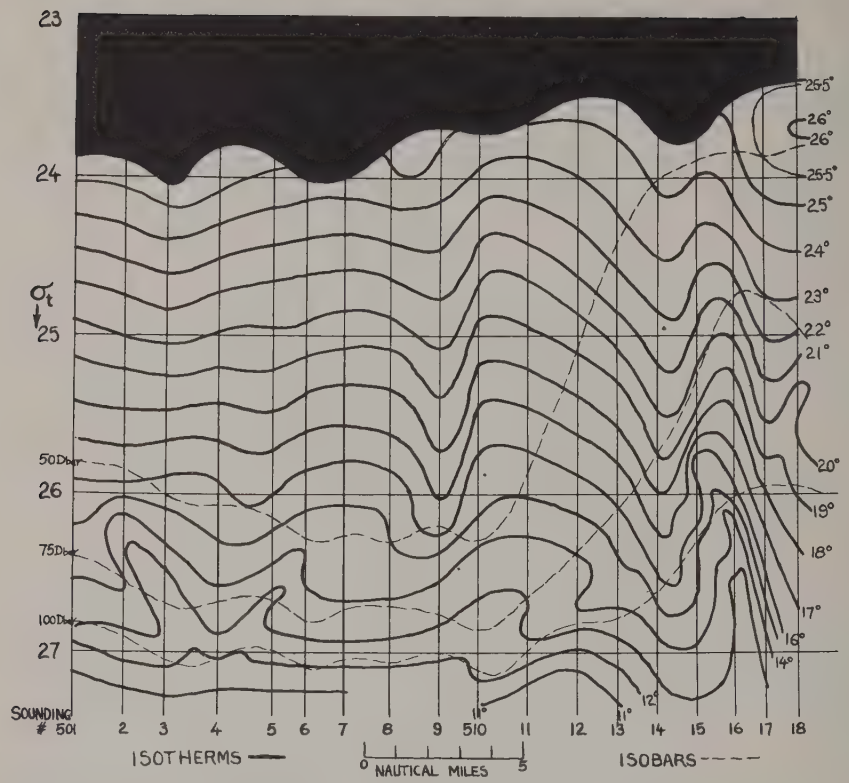

Fig. 6--Soundings on run perpendicular to Gulf Stream

Temperature-distribution on σ_t = 26.0--The distribution of temperature shows clearly the mutual intrusion of warm- and cold-water tongues (Fig. 3). The coldest parts of the cold-water tongues are found on the left and at the top of the grid while the warmest are at the right and bottom of the Figure; this suggests that the striated temperature is the result of cyclonic eddying motion and lateral shear. The "cold wall" of the Stream may be a statistical result of such eddy-like intrusions of cold slope-water.

The isobars on the surface as shown in Figure 4 show its configuration.

Oxygen-distribution--The distribution of oxygen is not shown here. Considerable doubt attaches to some of the oxygen-values which show great supersaturation. If, however, all supersaturated values are arbitrarily neglected as being the result of entrapped air in the sample-bottles or some such cause, the distribution of oxygen corresponds exactly to that of temperature--low oxygen in the warmer water and high values in the cold tongues.

This is brought out clearly in Figure 5 which shows the oxygen-temperature correlation for three different σ_t-surfaces. The linear correlation of temperature with oxygen for σ_t-constant shows that here only two distinct water-types are taking part in the mixing process and gives a definite picture of mixing in a σ_t-surface.

Cross-sections--The conventional sections which are used are not convenient for the study of water-types in a complex situation. In the foregoing study it was found that a cross-section employing σ_t as the vertical axis of ordinates was most suitable. Isotherms plotted on such a cross-section reveal at a glance the different water-types. (Lines of constant oxygen would

also be suitable.) Isobars may also be entered on the cross-section to show the relation to the depth-scale and to indicate the stability.

A cross-section of this type is shown in Figure 6 for the soundings taken on a run perpendicular to the Stream (No. 518 is in the Stream). This run was made after the storm which broke the series at sounding No. 500 and can therefore not be located exactly relative to the previous soundings. The navigational data indicates, however, that it cuts across the region analyzed in Figures 3 and 4. A single water-type on this kind of cross-section would have isotherms parallel to the σ_t-lines whereas the boundary between different water-types is clearly shown where the isotherms are markedly inclined to the σ_t-lines. The cross-section supports the foregoing analyses.

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SURFACE COOLING AND STREAMING IN SHALLOW FRESH AND SALT WATERS*

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Experimental work with thermally unstable air and liquids (Mal, 1931; Graham, 1933; Chandra, 1937; and others) has shown that the convection "cells" formed vary with the amount of shear, which is introduced either by the flow of the fluid or by the movement of its boundaries. Changes in the flight tactics of free soaring gulls over the open ocean show that the pattern of the convectional up-flow within air moving over warmer water varies with the wind speed (Woodcock, 1940). Since the air over warmer sea water moves in a fashion in part comparable to the experimental findings, it was thought that some similar motion might be observed in the water itself.

While looking for possibly related convectional changes in surface waters under natural conditions, it has been found that the first few millimeters of water on the surface of shallow bays and ponds (salt and fresh) on Cape Cod are almost continuously colder than the subsurface water under average fall weather conditions. Associated with this cooled surface film, when winds are blowing, there is invariably found a small scale streaming (Fig. 33) in which the whole surface of the water is divided into a rapidly changing pattern of currents running in lines roughly parallel to the wind direction. These streams are usually about a centimeter across, with a constantly varying distance (usually just a few centimeters) between parallel lines of flow. The surface water between the lines moves transversely to converge in the lines, where it presumably sinks. Individual lines grow or die away within a few seconds time; sometimes converging upon other lines, sometimes diverging and disappearing. The water in the streams themselves moves down-wind much faster than the water between them, which suggests that they are an accumulation of water from the surface film which has been exposed to a maximum of wind drag. This small scale linear streaming is seen on the surface of large waves in the open sea, as well as in comparatively sheltered bays and ponds (where attending thermal instability has been measured) and, in the

* Contribution No. 294, from the Woods Hole Oceanographic Institution.

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shallow water, it seems to supply a mechanism whereby cooled surface layers of water are drained off to lower depths.

One of the most outstanding features of this surface streaming is the rapidity of the transverse movement of the water as indicated by the lycopodium powder broadcast on the surface. When the powder is dusted over the water it moves into lines so quickly that, even in a moderate breeze, the eye can hardly detect the transition from random scattering to the linear pattern. The speed of this motion suggests that the first few millimeters of water are being drained off to lower depths very rapidly.

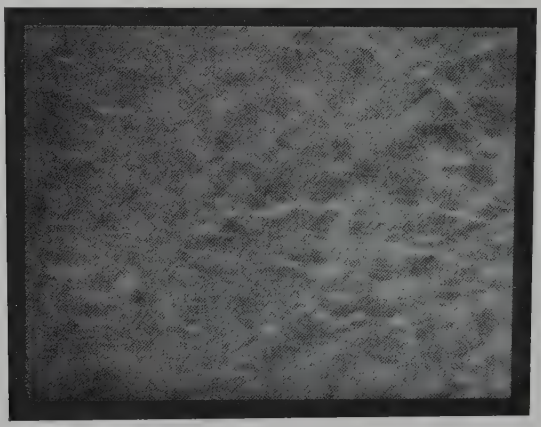

Figure 33. Surface streaming in a brackish pond, indicated by lycopodium powder.

Although the thermally unstable film on relatively open waters and the attending small scale streaming are not commonly recognized, experimental work in fluids by Rayleigh (1916), Phillips and Walker (1932), Mal (1931), and others has shown that thermal instability (introduced by heating below or cooling above), accompanied by sufficient shear, produces longitudinal strip-like convection cells extending in lines parallel to the direction of flow. In liquids they found that the motion was down in the lines and up between them.

Under natural conditions the cooled surface layer of sea water and lake water, plus the shear introduced by winds, apparently produces a patterned surface streaming comparable to the strip-like convection motions produced experimentally. Observations under natural con-

ditions have not been made when there was no possibility of heat loss from the surface film, so there is no positive assurance that the streaming cannot occur in stable water under a wind-produced shear. However, Brunt (1937, p. 283) remarks that ". . . shear does not of itself facilitate the formation of vertical circulations" in unstable air. Whether or not shear facilitates the formation of vertical circulations in stable salt and fresh surface waters remains unknown.

Langmuir (1938) made measurements of large scale surface streaming (5 to 25 meters between "streaks") in relatively deep water on a lake, and referred to it as "wind induced." He found sinking water

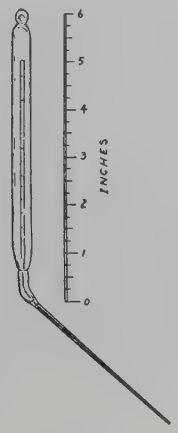

Figure 34. Thermometer used for making surface temperature measurements.

under the streaks and ascending water between them, and the slower moving surface water converged upon the lines transversely. He did not associate this motion with thermal instability, though he did say that during late fall "the descent of masses of denser water cooled by exposure on the surface" might accelerate it (p. 123).

The similarity of the surface motion in the small streams to the surface motion in Langmuir's streaks suggests that they may have a common origin, especially when we consider that the smaller is often found superimposed upon the other. In both cases, when winds are blowing, the surface water between the lines moves to the right and left of the wind to converge in the lines, and the down-wind motion of the water in the lines is faster than the down-wind motion of

the water between the lines. The experimental work in thermally unstable films indicates a need for both shear and instability for the formation of the strip-like lines of convergence. However, Langmuir's work on open water suggests that wind shear alone is enough. Perhaps the common occurrence of a rapidly produced unstable surface film on lakes and bays may serve to indicate a possible answer to the question raised, for it seems that this layer might supply the potential energy to drive the vertical circulations in Langmuir's "helical vortices" as well as in the experimental "cells."

Adney (1926) has demonstrated experimentally that the rate of solution of oxygen and nitrogen in de-aerated fresh and salt water is increased a great deal by vertical "streaming" due to surface cooling by evaporation. He found the resulting mixing more effective in salt water, which he said is due "largely if not wholly to the fact that in addition to the cooling effect of evaporation at the surface film, there is also that of concentration of the salts in solution" (p. 214). It seems reasonable to suppose that the surface cooling and streaming which is discussed here serves a similar purpose, under natural conditions, of carrying down oxygen and nitrogen saturated surface waters.

Variations in the spacings of the streams may prove useful as an indication of the depth to which the streams penetrate. In experimental treatment of the "strip" convection cells in unstable fluids, the horizontal dimensions are found to be twice the depth (or height) of the instability layer (Durst, 1932, p. 58). Casual observations of the distances between lines in surface waters on the open sea show that they vary from a few centimeters across up to 100 meters or more. Strip-like lines in air (indicated by mist rising from warm seas into cold air and by soaring gulls) show cell sizes varying from a few centimeters across up to several hundred meters.

An intensive study of the superficial surface water of seas and lakes seems justified, in view of the possible correlations between their various states of motion and temperature distribution, and the transfer of heat, momentum and gasses between the air and the water.

The following description of the methods and apparatus used so far will give the reader an idea of the preliminary nature of this first investigation and of some of the problems encountered. Also included is a table of data which shows the common occurrence of thermal instability in surface layers, and some of the conditions under which the surface cooling takes place.

A very sensitive Richter and Wiese mercurial thermometer (see Figs. 34 and 35) was used to measure the surface water temperatures. This thermometer has a bulb 1.5 mm. in outside diameter and 9 cm. long, and it is calibrated in degrees and tenths Centigrade. The small

volume and diameter of the thermometer bulb made it possible to measure temperatures quickly and within small depth ranges. However, it was necessary to stop wave action as much as possible in order to use this instrument satisfactorily. For this purpose a box 60 cm. square with a depth of 30 cm. was used (see Fig. 35). The absence of the bottom in the box allowed free vertical movement to the water inside the box. The grooves in the supporting legs made it possible to adjust the box level so that the edge of the box projecting above the water offered a minimum of interference with the air flowing past and at the same time stopped wave action. Only small waves could be stopped in this way, so it was necessary to work near a windward

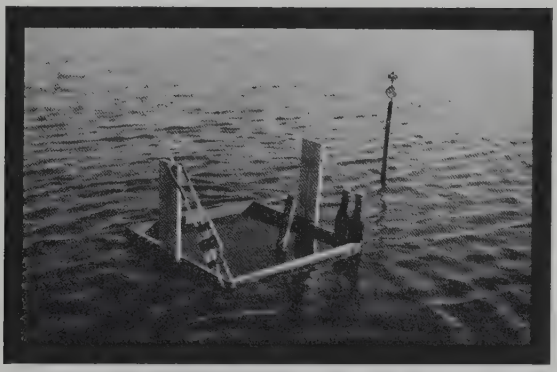

Figure 35. Wave damper in use.

shore (i. e. where the wind came from over nearby land) or during almost calm conditions. The average total depth of the water, where measurements were made, was about 70 cm. and at a distance of from 3 m. to 30 m. from the shore.

Water samples for chlorinity determinations were taken from the surface and at 2 cm. depth with two pipettes lashed together so that their tips were 2 cm. apart vertically (see Fig. 35). The tip of the pipette sampling the surface was ground at an angle so that while drawing in water one could draw in at the same time a stream of air bubbles. This was done to be sure that the pipette tip was held as nearly as possible at the surface. Tests in the laboratory at a vapor pressure difference* of 15 mb., showed that any excessive evaporation

* The saturation pressure of aqueous vapor over the sea water sample at water temperature — the aqueous vapor pressure at the temperature and relative humidity of the air in the laboratory.

due to this procedure was not measurable by the standard Knudsen method of chlorinity determination.

Wet and dry bulb measurements were made with a sling psychrometer; the thermometers of which are calibrated in whole degrees Fahrenheit. The readings were taken at about one meter above the surface of the water. Wind speed measurements were made at a height between 50 cm. and 100 cm. above the water (Fig. 35) with a single Casella anemometer. Correction for anemometer error has been applied to the readings.

Observations were made in a harbor where the salinity was about 30 °/₀₀, in a pond just above high tide level where the salinity was about 3 °/₀₀, and in an inland fresh water pond.

Table 1 shows all measurements tabulated according to increasing difference between the water temperatures at 3 mm. and at 20 mm. The first column gives the number of times temperatures were taken at the two levels (3 mm. and 20 mm.) and the figure in the third column is the average of the differences between these temperatures. Column two indicates whether the readings were made inside or outside of the wave damper. Saturation values of vapor pressure were taken from the Smithsonian Meteorological Tables (1933, table 79). Column four represents the saturation pressure of aqueous vapor at the water temperature at two cm. depth minus the aqueous vapor pressure at the temperature and the relative humidity of the air at one meter above the water. Column six lists the difference between the water temperature at one cm. below the surface and the air temperature at one meter above the surface.

The minimum depth (i. e. 3 mm.) at which temperature observations were made in the water is only roughly correct. In making readings in the surface film, the thermometer was adjusted manually so that there was always a layer of water visibly flowing over the top of the thermometer bulb. It is probable that the depth at which the surface temperatures were made varied from 2 mm. to 4 or 5 mm. depending upon the size of the small surface ripples. The 20 mm. level was determined by marking a centimeter scale on the stem of the thermometer; zero depth being at the level of the bulb of the thermometer.

The lack of a clear correlation between the degree of surface cooling (as expressed in the values in column 3) and the cooling factors measured (columns 4, 5 and 6) is attributed in part to inaccuracies in the depth of the thermometer bulb in making surface film temperature readings; also to unknown factors such as possible variations in the rate of sinking of the cooled water with different wind speeds; differences between the rates of sinking of the cooled water inside and outside of the box; variations in solar radiation; variations in radiation

absorption and emission of the surface water itself; and the possible influence of different amounts of particulate matter in the water on some of these factors.

In the beginning of this work it was thought necessary to make many chlorinity determinations in order to prove that the colder surface film was not also fresher, hence stable. However, when comparable layers of colder water were found on sea water, on brackish water and on fresh water during the same day under approximately the same weather conditions, it was thought unnecessary to continue the chlorinity titrations. Several times, during the observations in salt water, samples were taken as previously described. These samples showed no marked difference between the salinity at the surface and that at 2 cm., though most of the time the surface proved to be slightly more saline. Tests were made with samples drawn from outside the box as well as inside, though of course samples from outside the box could be taken only near a windward shore or during almost calm conditions.

Temperatures taken inside and outside of the wave damping box, when conditions permitted, showed that the cooling of the surface water was not confined to the inside of the box, but was general over the water surface outside as well. The curved lines connecting the "ins" and "outs" in column 2 indicate series of observations which were made inside and outside of the box under otherwise approximately the same conditions. These transitions were made in fresh as well as salt water. It is not suggested here that the wave damping box does not affect the enclosed water, but merely that the cooled surface layer which is measured in it is roughly comparable in depth and degree to the cooled surface layer on the outside, under the indicated weather and other conditions.

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TABLE I

TEMPERATURE READINGS AT 3 MILLIMETERS AND AT 20 MILLIMETERS. OBSERVATIONS ARRANGED IN ORDER OF INCREASING THERMAL INSTABILITY

1	2	3	4	5	6	7	8	9	10
Number of readings	*Inside or outside of box*	*Av. $T_{3\,mm.}$ −Av. $T_{20\,mm.}$ °C*	*Vapor Press. mb.*	*Wind m sec^{-1}*	*$T_W - T_A$*	*Cloudiness 1–4*	*Water*	*Time E.S.T.*	*Date 1940*
15	in	+0.1	0.8	4.7	−0.7	hazy	Salt	1040	Oct. 15
11	out	0.0	3.1	4.7	−1.0[5]	1	Brackish	1150	Oct. 15
27	out	−0.1	1.5	1.3	+0.3[5]	4	Salt	1515	Oct. 8
9	out	−0.2	3.4	4.4	0.1	hazy	Brackish	1455	Oct. 13
22	in	−0.2	4.6	4.2	0.0	2	Salt	1200	Oct. 6
14	in	−0.2	7.0	2.4	2.7	2–3	Salt	1015	Sept. 12
10	in	−0.3	5.4	3.4	0.8	0	Salt	0855	Sept. 28
4	out	−0.3	6.0	5.1	1.8	4	Salt	1540	Oct. 2
8	out	−0.3	13.0	0.7	0.7	0	Fresh	1150	Oct. 14
7	in	−0.3	5.9	3.6	2.7	0	Brackish	0950	Oct. 19
18	in	−0.3	6.0	5.1	1.8	4	Salt	1500	Oct. 2
13	in	−0.3	7.7	4.8	1.0	2	Brackish	1215	Oct. 18
39	in	−0.3	6.2	1.7	0.0	2	Brackish	0900	Sept. 19
10	in	−0.3	9.3	3.2	2.1	1	Salt	1135	Oct. 10
8	out	−0.3	9.3	3.2	2.1	1	Salt	1155	Oct. 10
22	in	−0.3	8.0	2.7	1.1	0	Salt	1105	Sept. 27
13	in	−0.4	13.0	0.7	0.7	0	Fresh	1210	Oct. 14
9	in	−0.4	3.6	4.1	1.1	hazy	Brackish	1620	Oct. 12
5	out	−0.4	13.0	0.7	0.7	0	Fresh	1220	Oct. 14
25	in	−0.4	8.0	2.0	1.7	0	Salt	0920	Sept. 13
8	in	−0.4	6.2	1.8	0.7	1	Salt	0650	Sept. 18
20	in	−0.4	7.3	3.9	1.8	0	Salt	0900	Sept. 27
7	in	−0.5	8.6	4.9	4.9	0	Salt	1115	Oct. 16
7	out	−0.5	8.9	3.3	1.4	4	Salt	1300	Oct. 9
20	in	−0.5	9.6	2.1	0.0	0	Salt	0950	Oct. 14
10	in	−0.5	13.1	1.5	10.0	0	Fresh	1140	Oct. 19
5	in	−0.5	8.9	3.3	1.4	4	Salt	1245	Oct. 9
11	in	−0.6	11.0	2.1	5.9	1	Fresh	1120	Oct. 18
5	out	−0.6	11.0	1.0	13.4	2	Fresh	2310	Oct. 10
7	in	−0.6	9.3	0.8	4.2	1	Fresh	1615	Oct. 10
23	out	−0.6	9.3	0.8	4.2	1	Fr sh	1540	Oct. 10
21	in	−0.7	8.7	2.5	1.8	0	Brackish	0750	Sept. 23
10	in	−0.7	9.0	6.6	3.9	0	Brackish	0940	Sept. 26
12	out	−0.7	13.1	0.9	10.0	0	Fresh	1055	Oct. 19
12	in	−0.7	8.4	3.6	2.9	0	Salt	1025	Oct. 18
1	out	−0.8	12.7	0.8	11.9	0	Fresh	2130	Sept. 29
6	out	−1.0	9.9	0.9	9.7	1	Fresh	2230	Oct. 15

THE ANGULAR DISTRIBUTION OF CHARACTERISTIC DIFFUSE LIGHT IN NATURAL WATERS*

By

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INTRODUCTION

Several investigators have conducted experiments on the angular distribution of light in natural waters (*1*, *2*). It has been found that the direction of maximum light intensity from the sun moves toward the vertical with increase in depth. It has also been found that light becomes more diffuse but remains highly directional with increase in depth. Clarke has pointed out the biological importance of the directional properties of deep water illumination (*3*). The purpose of this article is to add to the information extant on the angular distribution of light, and to present evidence that at great depths a limiting angular distribution pattern of intensity is approached. This pattern is defined as that of *characteristic diffuse light.* In another paper the author has developed a general law for the diminution of light intensity based on this concept (*4*).

FIRST MEASUREMENTS

Figure 25 shows light intensities measured in a vertical plane for 3, 6, and 9 meters. Figure 26 shows measurements in a horizontal plane for the same depths. These readings were taken in Trout Lake, Wisconsin in August 1937 with a photocell and amplifier described by the author in an article on the microstratification of inland lakes (*5*). A cylindrical hood over the apparatus confined the light received to an angular opening of about 15 degrees. The apparatus was suspended by a bifilar suspension at a given zenith angle, and then rotated in a horizontal plane. In Figure 25 the intensity from beneath is made arbitrarily equal to one for all depths. On this scale the intensity from above increases from 40 units at 3 meters to 100 units at 9 meters. The intensity from the direction of the solar beam decreases from 190

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units at 3 meters to 138 units at 9 meters. In Figure 26 the intensity in a horizontal plane in a direction opposite the sun has been made equal to one unit for all depths. Toward the sun, the intensities are about four, three, and two units respectively in order of increasing depth.

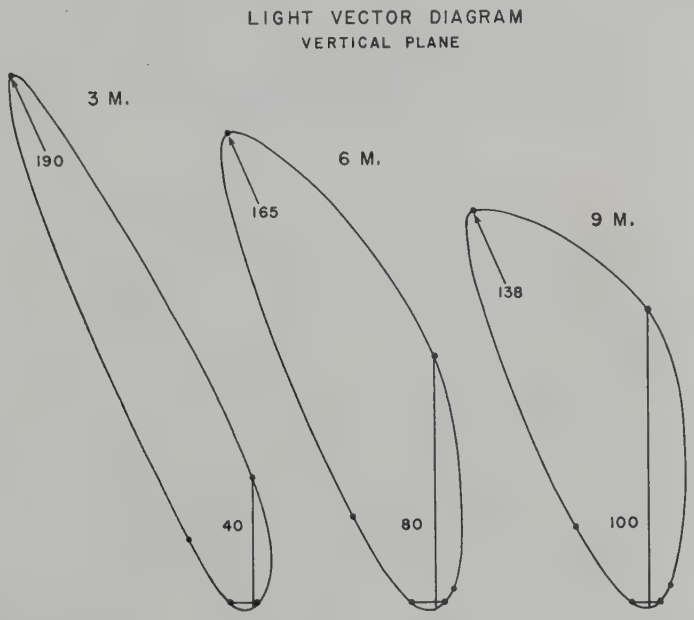

Figure 25. Light vector diagram in vertical plane including sun. Trout Lake, Wisconsin, August 1937.

The relative increase in light intensity from above as compared with the decrease from the direction of the solar beam is unmistakable. The measurements in the horizontal plane show that the light intensity becomes more symmetrical about a vertical axis as depth increases.

MEASUREMENTS WITH ROTATING PHOTOCELL

It became evident when using the original apparatus that measeurments should be taken at close intervals in the vicinity of the maximum intensity. It also seemed advisable to revise the apparatus for rapid

rotation in a vertical plane. As a matter of fact, speed in readings is of the utmost importance since the zenith angle of the sun changes continuously. This angular change is often greater than the change one is attempting to measure. High sensitivity is also of utmost importance.

The new apparatus consisted of a water tight brass cylinder which contained a photocell, amplifying tube, three small dry cells for C

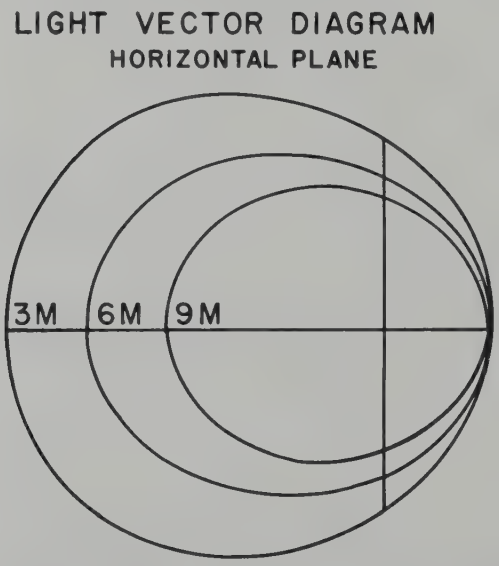

Figure 26. Light vector diagram in horizontal plane. Trout Lake, Wisconsin, August 1937.

bias, and a rotating screen which permitted different amounts of light to enter the photocell. The screen was controlled by an electromagnet. A hood with several diaphragms to eliminate reflected light confined the light received to a 15 degree angle. The cylinder was connected to the control box by means of a 100 meter four wire cable. The control box contained a second stage of amplification, necessary meters, and batteries. The circuit was similar to the one used in micro-stratification work. The cylinder was free to rotate on a horizontal axis and was supported in a frame which hung vertically from a

bifilar suspension. A ratchet mechanism attached to the cylinder caused a rotation of 10° each time a cord was pulled. After the last pull, the cylinder automatically returned to the starting position by action of a spring. The work with this apparatus was done at the Woods Hole Oceanographic Institution.

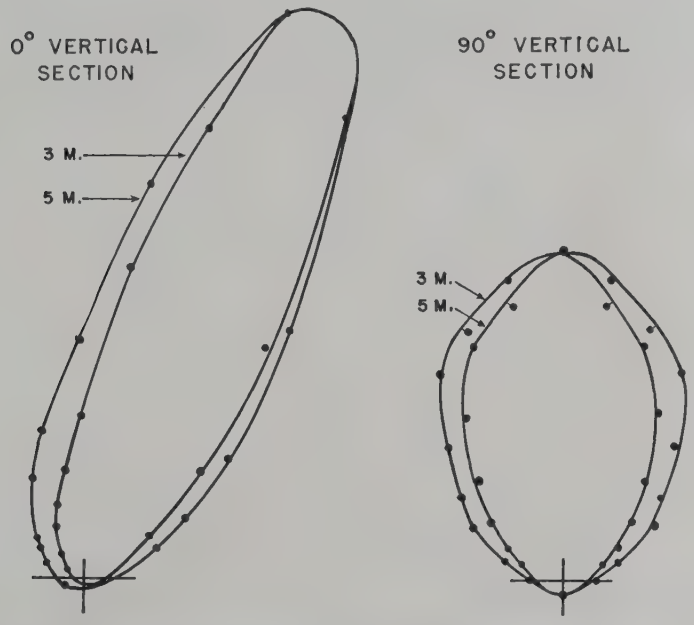

Figure 27. Vertical section light vectors. Woods Hole Harbor, August 23, 1939.

Figure 27 shows readings taken August 23, 1939 in Woods Hole Harbor at 3 and 5 meters in depth. The 0° vertical section is the vertical plane including the sun; at right angles to this plane is the 90° vertical section. For purposes of comparison the maximum readings are made to coincide. It has been stated that light becomes more diffuse in deep water; the contrast between these two sections suggests a new meaning to the idea of diffuseness in natural waters. The pattern of the 0° vertical section is broader at 5 meters than at 3 meters, while the 90° pattern is just the reverse, being narrower at 5 meters. Probably an equilibrium condition is being approached in

which light intensity tends to become symmetrical about a vertical axis.

Further evidence of this fact is to be found in certain readings of the 0° vertical section. The ratio of the 90° zenith angle reading, to the 270° zenith angle reading, or the horizontal reading toward the sun compared to the horizontal reading away from the sun, becomes closer to unity at greater depths. This ratio is 2.1 at 3 meters and 1.4 at 5 meters. The ratio of the maximum reading to the 0° zenith angle also tends to approach unity. The values of this ratio are 3.8, 2.4, and about 1.4 at depths of 3, 5, and 8 meters respectively.

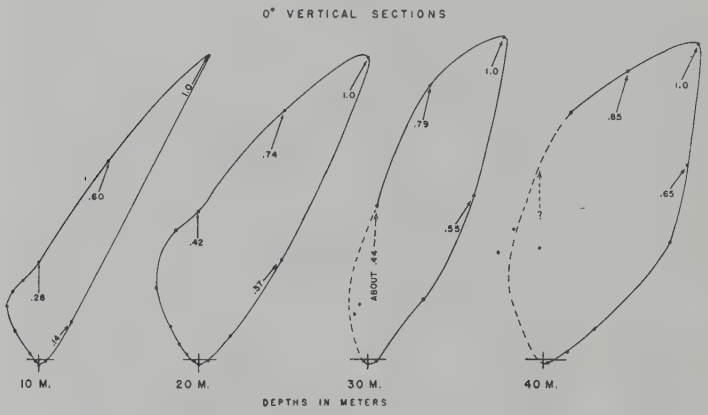

Figure 28. Vertical section light vectors. Taken just beyond Continental Shelf, September 2, 1939.

The second set of readings was taken from the research ship, Atlantis, just beyond the Continental Shelf at 39° 34′ N. latitude and 71° 05′ W. longitude. The water was more transparent and had fewer scattering particles than the Woods Hole Harbor water. The Atlantis did considerable rolling and pitching, but readings were sufficiently definite to confirm the tendencies shown by the first set of readings in Woods Hole Harbor. The apparatus was suspended from a boom over the stern of the vessel. Figure 28 shows 0° vertical sections with the maximum reading for each depth set equal to unity. The proportionate 0° zenith angle reading and the readings each side the maximum are shown numerically on the figure. The zenith reading becomes relatively greater in deeper water. The readings each side the maxi-

mum also become relatively greater; in other words, the maximum become broader. Under the experimental conditions any attempt to measure accurately the shift in zenith angle of maximum intensity was out of the question, but there was some shift toward the zenith with depth. There is no question that the pattern broadened with depth.

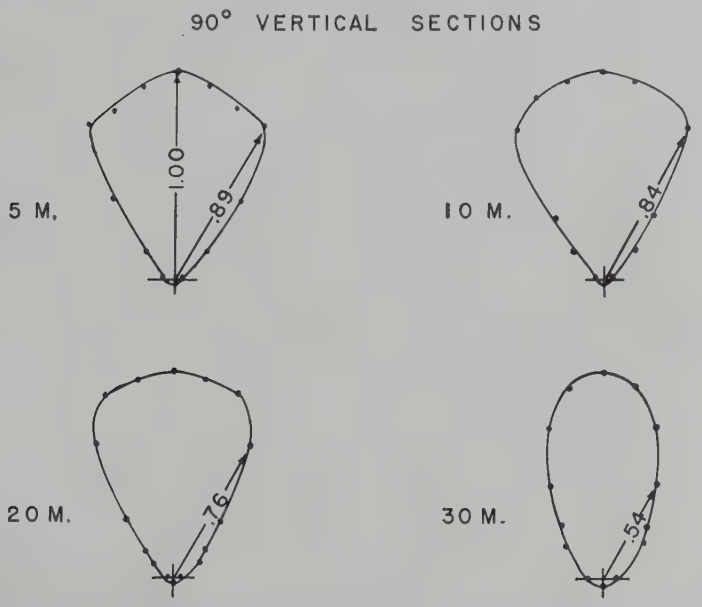

Figure 29. Vertical section light vectors. Taken just beyond Continental Shelf, September 2, 1939.

The 90° vertical sections illustrated in Figure 29 also show the reverse tendency as depth increases. For purposes of comparison, the 30° zenith angle reading is expressed in terms of the maximum. For example, a large 30° reading relative to the maximum would mean greater diffusion in the sense of equality of light from all directions. But as depth increases, or, as the diffusion approaches the maximum amount possible, the light becomes more directional from the zenith. The broader tops of the shallow water curves are probably due to the fact that the refracted rays from the sky have not as yet lost their

predominance. At 30 meters the direct rays from the sky have become relatively insignificant. An elongated oval-like pattern is approached which is evidence of the small amount of scattering in this water. Since the pattern represents approximately the maximum diffusion in deep water, it may be defined as that of characteristic diffuse light. The idea that maximum (or ultimate) diffusion means equality of

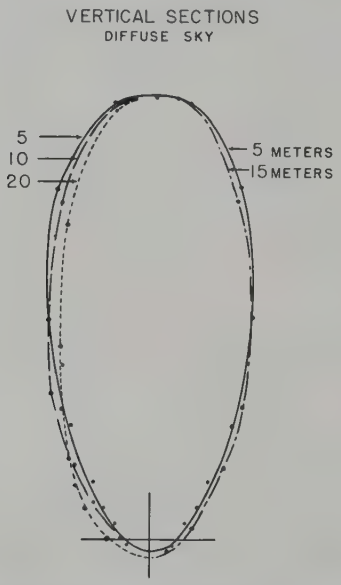

Figure 30. Vertical section light vectors under conditions of evenly clouded sky. Taken ¾ mile SSE of Tarpaulin Cove Light in Vineyard Sound, August 26, 1939.

light intensity in all directions ignores the fact that the light source itself must be in some particular direction.

The readings shown in Figure 30 were taken with a completely clouded and diffuse sky. The sun was entirely obscured and only one vertical section was taken. It was assumed that other vertical sections would be the same. The readings were obtained about ¾ miles S. S. E. of the Tarpaulin Cove Light in Vineyard Sound. It might be expected that these curves should be similar to the 90° vertical section curves of Figure 29 since a clouded diffuse sky and a clear uniform blue sky

should furnish approximately equal light intensities at all angles. However, the water beyond the continental shelf was clearer and subject to less scattering; hence the slower loss in the directional properties of the sky light as contrasted with the more rapid loss in the Sound. That this rapid loss is due to the character of the water and not to the condition of the sky is shown in the 90° vertical section of Figure 27. These readings were taken in bright sunlight but there is a rapid loss of the directional properties of the sky radiation due to the higher turbidity of the water in Woods Hole Harbor. As a matter of fact, there is little evidence of a broad top to the curve even at 3 meters.

Several interesting facts stand out upon a careful examination of Figure 30. There is a regular change in the curves as deeper water is reached; the upper portions become uniformly narrower, the lower portions broader. It seems obvious that there must be a limit to this process; it may be that the limiting pattern is symmetrical not only about a vertical axis but also about a horizontal plane as well. This possibility suggests theoretical investigation.

The fact that the changes are small seems good evidence that the pattern is practically that of characteristic diffuse light. The shape of this pattern probably depends on the relative values of the absorption and scattering coefficients. Possibly a theoretical derivation of such characteristic curves can be worked out.

It seems reasonable that the characteristic pattern will be approached rapidly, or within a short distance of the surface, if total absorption or scattering is large. The shape of the pattern approached should depend on the relative values of the absorption and scattering coefficients.

In Figure 30 and in many other sets of readings taken, it has been found that the reading vertically downward is approximately half the reading taken in a horizontal direction. This seems to be true where readings are symmetrical about a vertical axis as, for example, when readings are taken in deep water. Of course, light intensities directed upward in deep water are often too faint to be reliable. The following approximate and incomplete line of reasoning, however, suggests that there may be some significance to this two to one ratio of intensities. Assume that a light receiver has unit cross section and that it receives light in a horizontal direction from a column of unit cross section extending an infinite distance horizontally from the receiver. Assume also that the total light striking the receiver is the summation of all the amounts scattered toward the receiver, and reduced in accordance with the exponential law. This gives for the horizontal intensity:

$$I_h = \int_0^\infty fI'e^{-kv}dy = fI'/k.$$

The amount scattered *from* each contributing element of volume is proportional to I' the total light intensity at the level of the contributing elements and which is constant for this integration, to dy the thickness of each contributing layer, and to f a constant of proportionality which is a measure of the scattered light sent toward the receiver. The amount contributed from below yields a similar expression with the single exception that the light intensity at the level of the contributing elements is no longer constant but equals $I'e^{-kx}$ where I' remains the light intensity at the level of the receiver. Performing this integration the intensity upward is:

$$I_u = fI'\int_0^\infty e^{-2kx}dx = fI'/2k.$$

This is half the horizontal intensity. This treatment assumes that f, the proportionality constant for scattered light, is the same in all directions. This assumption is discussed by the author in the paper on the general diminution law (*4*).

DISCUSSION

Measurements of the angular distribution of light in natural waters show that as light reaches greater depths the directional properties of the refracted sun and sky light become less important. Light intensities in a vertical plane passing through the sun, or in the 0° azimuthal plane, show diminishing intensities toward the sun and a general broadening with depth. Readings taken in the 90° azimuthal plane, or readings taken in a vertical plane when the sky was uniformly clouded, showed a narrowing of the pattern with depth. In both planes the relative intensity toward the zenith increased. In all cases a pattern which is symmetrical about a vertical axis is approached in deep water.

The limiting angular distribution pattern seems to be oval shaped, possibly symmetrical about a horizontal plane as well as about a vertical axis. The exact shape of the pattern is probably a function of the scattering and absorption coefficients. Experiment and theory lead to the belief that a reading taken with the receiver face down should be half the reading in a horizontal direction.

SUMMARY

1. The angular distribution of light intensity was studied in Trout Lake, Wisconsin, Woods Hole Harbor, beyond the Continental Shelf, and in Vineyard Sound.

2. Evidence pointed to a limiting pattern in each case. The pattern is defined as that of *characteristic diffuse light.*

3. The pattern is approximately oval shaped and elongated toward the zenith.

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STUDIES ON THE GROWTH OF INTEGUMENTARY PIGMENT IN THE LOWER VERTEBRATES

I. The Origin of Artificially Developed Melanophores on the Normally Unpigmented Ventral Surface of the Summer Flounder (Paralichthys dentatus) [1]

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Considerable evidence has accumulated to indicate that melanophores may be grown experimentally on certain fishes and amphibians in areas where these cells fail to develop naturally. Cunningham (1891, 1893, and 1895), working with several species of flatfishes; von Frisch (1911), using *Esox* and *Nemadulus;* and Osborn (1940*a*, *b*, and *c*), studying the summer flounder (*Paralichthys dentatus*) and the common bullhead (*Ameiurus melas*) have all reported success in growing melanophores on the normally unpigmented ventral [2] surfaces of these teleosts. Experimenting with the urodele, *Salamandra maculosa,* Herbst and Ascher (1927) were able to develop abnormal amounts of pigment ventrally. In spite of these observations the origin of the newly developed melanophores has remained an open question. Alternative possibilities are obvious: either they differentiate *in situ* or they migrate in from other areas.

This paper brings together the results of experiments referred to in an earlier report (Osborn, 1940*a*) designed to gain more information concerning the source of experimentally developed melanophores.

Materials and Methods

A freshly caught stock of adult flounders 15 to 18 inches long was maintained to avoid abnormal conditions in pigmentation which sometimes arise from prolonged sojourns in unnatural laboratory surroundings. The desired amount of pigmentation was developed ventrally in

[1] Contribution No. 296 of the Woods Hole Oceanographic Institution, whose research facilities and financial aid provided for this investigation are genuinely appreciated.

[2] The term "ventral" will be used to refer to the lower normally unpigmented surface of the animal. In the flatfishes the unpigmented side is more strictly the right or the left side, depending upon the species. In the summer flounder the right side is white.

an apparatus similar to that previously described (Osborn, 1940*a*) with minor improvements. When a fish was sacrificed, at least 40 scales plucked from widely separated areas on the ventral surface were fixed in 5 per cent neutral formalin. Of these, ten were dehydrated in alcohol, cleared in xylol and mounted in Clarite; ten were mounted in glycerine jelly directly following fixation; and 20 were treated according to Laidlaw's modification (1932*a*) of Bloch's (1917) "Dopa"[3] reaction. These preparations were finally mounted in balsam. All scales were studied by both transmitted and reflected light and photographic records made. Appropriate control preparations were reserved for each condition. The ventral surface was carefully examined for pigmentation with a dissecting microscope before each animal was sacrificed and daily observations were made during longer experiments.

Experimental

In connection with studies previously reported (Osborn, 1940*a*), it was observed that experimentally developed melanophores appeared in random positions and patterns on the ventral surface. Pigmented spots of macroscopic size and irregular in shape, differing in intensity from gray to black, appeared here and there over any part of the ventral surface. The only position where melanophores developed with considerable regularity was at the base of the tail. In this area normal control fishes also usually possess some pigment, probably because considerable light reaches this narrow region where the surface is somewhat rounded and unprotected by fins.

The "Dopa" Reaction

This reaction first described by Bloch (1917) and later modified by Laidlaw (1932*a*) has been used for the identification of melanoblasts. Although these cells contain no melanin pigment, Bloch observed the formation of a black substance which he called "dopa-melanin" when treated with "Dopa." He believed this was due to an oxidizing ferment, dopa-oxidase, in the cell which reacted with the "Dopa." Thus, many investigators have interpreted the "Dopa-positive" cell as a potential melanophore even though it had not yet differentiated.

In order to test ventral scales for the presence of melanoblasts by the "Dopa" technique, three groups of flounders (12 fishes in each group) were chosen. The first group was black-adapted, then totally blinded and finally illuminated ventrally to insure optimum conditions

[3] Throughout this paper the term "Dopa" will be used to refer to 3–4 dihydroxyphenylalanin (levorotatory).

for rapid growth of melanophores (Osborn, 1939, 1940*a*). This treatment was continued until considerable ventral pigment had developed (Fig. 6). When a random sampling of ventral scales from such a fish was studied it became apparent that all degrees of pigmentation (melanogenesis) were represented by the various scales (Figs. 8, 9, and 10). In some scales there were no melanophores, in others the small number of melanophores had only scattered melanin granules while still others were melaninated so heavily as to be indistinguishable from scales plucked from the dorsal surface. Such scales arranged in a progressive series show all stages in the acquisition of a full complement of melanin in melanophores, suggesting that the process of pigmentation occurs in the cells *in situ* as they differentiate on a particular scale. Furthermore, there appears to be no tendency for scales adjacent to naturally pigmented areas (the edges of the fins etc.) to become pigmented first with subsequent spreading from originally pigmented surfaces. Rather, melanophores suddenly appear containing a few pigment granules quite independently of neighboring cells. In an attempt to obtain more than circumstantial evidence on this point some scales possessing no melanin-containing cells (microscopic examination—Fig. 2) and others containing but few young melanophores (the exact number and their position on the scale recorded in each instance) were subjected to the "Dopa" treatment. An average of 14 out of 20 scales from each of the 12 fishes gave a positive "Dopa" test (Fig. 3).[4] In some ventral scales positive cells were as numerous as the melanophores on dorsal scales while in other instances only scattered cells responded positively. An entirely satisfactory explanation for the failure of some scales to react positively cannot be given. Two possibilities are suggested: either these scales possessed no melanoblasts, as is apparently the case in scales occasionally found on the dorsal surface, or the technique may not be entirely dependable even though precautions were taken that the solutions were fresh and the incubation temperature accurately controlled.

The flounders in group 2 were illuminated ventrally for a shorter period (4 to 10 days), only until the first appearance (macroscopic) of partially pigmented scales here and there over the surface. For the "Dopa" test scales were chosen which possessed no melanin-containing cells or but few melanophores (again carefully recorded). In this group an average of 16 out of 20 scales per animal responded positively. The range of variation was wide as in the first group.

[4] It is of interest to note that these "Dopa" positive cells appear similar to the round melanoblasts pictured by Laidlaw (1932*b*; Fig. 5, Plate 84; and Fig. 8, Plate 85) in human skin.

The third set of flounders was not subjected to ventral illumination or any other laboratory conditions. They were used immediately without allowing time for adaptation to any unnatural background. Adequate scales were plucked from the ventral surface for each of the three types of preparations previously listed and routine "Dopa" tests were run. None of the cells of the scales used possessed microscopically detectable melanin granules. An average of 13 out of 20 scales from each fish reacted positively to "Dopa." Again the range of variation in the number of positive cells from scale to scale was wide. It is of considerable interest, however, that flounders taken directly from nature should possess numerous potential melanophores on a surface so free from melanin.

Observations Using Transmitted Light

A brief summary follows for the microscopic observations of ventral scales studied by transmitted light. Some were mounted in glycerine jelly to preserve the alcohol-soluble pigments; others were mounted in Clarite following dehydration and xylol clearing.

In glycerine mounts the numerous leucophores appear slightly opaque (Fig. 2) because of their content of guanin crystals and may be easily recognized by their relative numbers, irregular (dendritic) shape and their size. Other cells, less numerous, flattened, and smoother in contour, almost round (in fact having the same shape as those which reacted positively to "Dopa"), could be seen scattered among the leucophores. They are believed to be melanoblasts and are best seen when the iris diaphragm is partly closed. Young melanophores, containing few melanin granules, are of much the same appearance but usually are given a slightly more irregular form by the extensions of simple processes. In studying scales arranged in series progressing from those having no melanophores to scales possessing numerous melanin-containing cells there appears to be a direct correlation between the increase of melanin contained in the cell and the complexity of the processes. A coincidence observed so regularly that it should not be overlooked was that wherever several melanophores were growing in a group the absence of leucophores in that spot was strikingly obvious (Figs. 9 and 10). Viewed with reflected light this was even more easily seen. This suggests that in some way a substitution of melanophores for leucophores may take place or that conditions in the tissues favoring the generation of new melanophores may also be responsible for the degeneration of leucophores. Can it be that leucophores change into melanophores? The very existence on the dorsal surface of structures which apparently

contain both melanin and reflecting material (probably guanin) is evidence supporting the idea that two pigments may occur within a single cell (melanoleucophore—Figs. 4 and 5).

It was noted also that in scales possessing many melanophores the cells appeared to be larger and more complex with more numerous, irregular processes in contrast with other scales which had perhaps a half dozen or less melanophores usually of uniform small size and simple pattern, apparently less highly differentiated. To a certain extent the melanophores on a particular scale tend to differentiate more or less synchronously. The way in which experimental pigmentation first appears on the ventral surface of the flounder seems to be in harmony with this and with the evidence gained in the "Dopa" tests. In addition, occasional cells containing some yellow pigment (xanthophores) were seen.

Clarite mounts showed essentially the same picture except that no xanthophores were detected. The leucophores were much more transparent but could be recognized by reducing the light. The smaller round cells were also visible.

Observations with Reflected Light

Glycerine mounts viewed with reflected light showed the leucophores in clear relief but to the disadvantage of the other cells present. However, in cases where some melanophores had developed among the leucophores, the negative outline of the melanin-containing cells could be followed, aided somewhat by the absence of leucophores at that site (see previous page and Figs. 9 and 10). Now and then xanthophores were observed by reflected light.

The scales cleared and mounted in Clarite were less instructive when viewed with reflected light. Because their relative transparency reduced the clarity of the reflected image, they supplied little additional information.

Observations Concerning Regenerating Scales

In areas of injury on the ventral surface where scales had been scraped away, the newly regenerated ones appeared darkly melaninated if the fish was maintained in a physiological and experimental condition favorable to the development of ventral pigment. Such scales are black with melanophores as they appear (Fig. 7). However, if the injured flounders are white-adapted or on a pale natural background with normally alternating night and day (not excessive illumination), the regenerating ventral scales will be white with leucophores and possess no

PLATE I

Explanation of Figures

Fig. 1. White ventral surface of a freshly caught summer flounder. Note that the scales are normally covered with leucophores (containing guanin) but that melanophores fail to develop on this surface. About ⅙ natural size.

Fig. 2. Photomicrograph of a scale (mounted in glycerine) plucked from the ventral surface of a normal summer flounder. This scale possessed no melanophores. The numerous gray-appearing cells are leucophores which appear slightly opaque when photographed with transmitted light. About 20 ×.

Fig. 3. Photomicrograph of a scale which reacted positively to the "Dopa" treatment. The densely opaque cells which have deposited dopa-melanin are interpreted to be melanoblasts. Before treatment this scale appeared similar to that in Fig. 2. About 20 ×.

Fig. 4. Photomicrograph (*transmitted* light) of a small area of the tip of a scale plucked from the center of a white "excitation spot" on the dorsal surface of a black-adapted flounder. The melanophores are numerous even in this white area but are only slightly dispersed and well concealed by guanin crystals, as will be seen in Fig. 5 taken with reflected light. Cell "x" is the same structure marked for purposes of orientation in Figs. 4 and 5. About 100 ×.

Fig. 5. The same area as shown in Fig. 4. This photograph was made with *reflected* light, however, Note that the total area appears relatively white as it would on the fish in reflected light even though the scale is heavily melaninated. The reflecting guanin appears to be within the bounds of the melanophores because the cells retain a constant size and shape when viewed by reflected and transmitted light. Such a structure is referred to as a "melanoleucophore." Compare Figs. 4 and 5 cell for cell. About 100 ×.

Fig. 6. Ventral view of summer flounder blinded immediately after capture and continuously illuminated ventrally (direct light). Although this fish was illuminated only 18 days, its melanination is nearly as extensive as on the flounder shown in Fig. 7. This is due to the greater efficiency of direct illumination. One-sixth natural size.

Fig. 7. An area of ventral surface adjacent to the pectoral fin. The flounder was black-adapted, blinded, and illuminated continuously 74 days in a white tank. Widespread melanophore formation has occurred but pigmentation is blackest where regenerated scales have grown in an injured area from which the scales had been scraped. One-third natural size.

Fig. 8. Photomicrograph of the tip of a dorsal scale plucked from one of the white "excitation spots" of a black-adapted flounder. The numerous melanophores are only slightly distended during excitation despite the fact that the fish had been black-adapted several days. Scales possessing comparable melanination are commonly found in the darker pigmented areas ventrally. About 50 ×.

Fig. 9. Photomicrograph of part of a scale plucked from a lightly melaninated area of the ventral surface of a summer flounder black-adapted 7 days, blinded and placed in a white tank constantly illuminated from overhead for 12 days. The photograph was taken with *transmitted* light. The few young melanophores present appear in distinct contrast to the numerous leucophores which cover nearly the entire scale surface. Note that the leucophores are absent from the newly melaninated area. Melanophore "a" serves as a point of reference and orientation in Figs. 9 and 10. About 40 ×.

Fig. 10. Same area shown in Fig. 9. Photographed with *reflected* light, the numerous leucophores appear white as on the lower surface of the normal flounder. They contain no melanin and are true leucophores. The melanophores are visible only because they reflect the least light and appear black in contrast with the rest of the scale surface. Compare Figs. 9 and 10. About 40 ×.

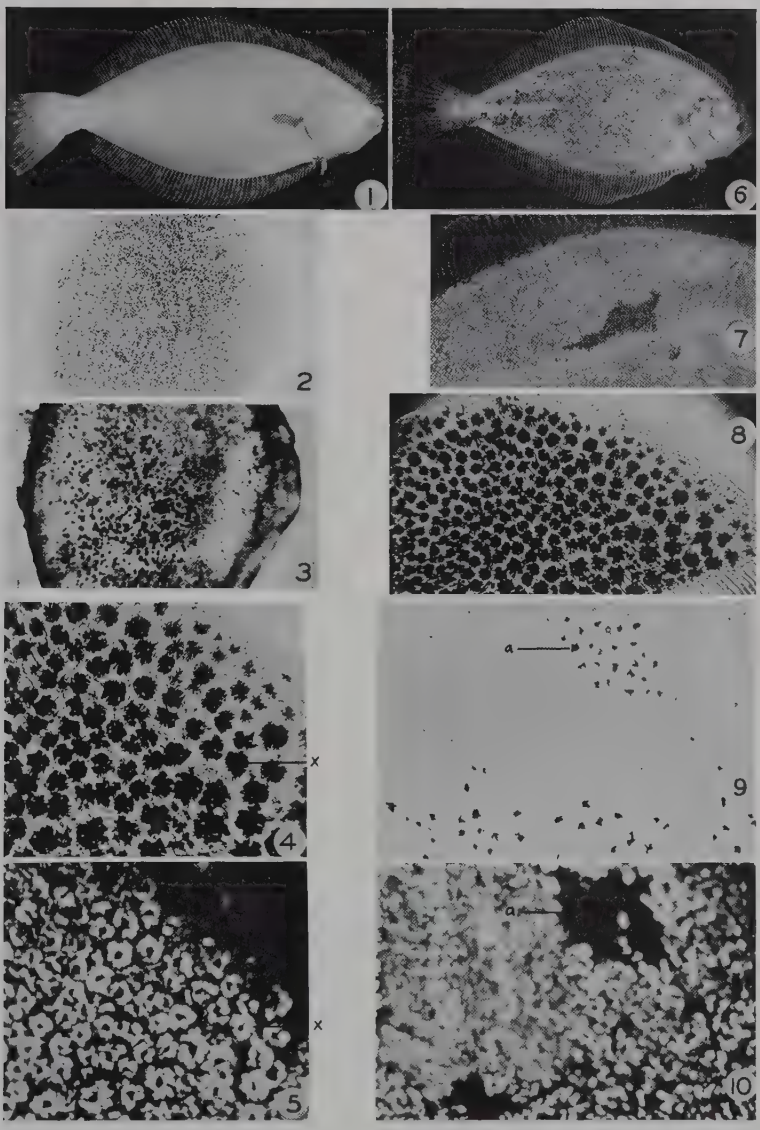

PLATE I

melanophores. On the other hand, if the dark flounders are injured, then placed immediately in the apparatus providing ventral illumination, the scales which regenerate appear as some of the darkest on the entire ventral surface. Although the reason for this is not definitely known, it may be that the numerous leucophores on the white scales tend to mask the developing melanophores during their early stages. The prompt appearance of melanin-containing cells in areas of repair far removed from normally pigmented regions lends further support to the *in situ* origin of ventral melanophores and makes the possibility of migration from previously pigmented areas seem very improbable.

Discussion

That melanophores may be grown under proper experimental conditions on surfaces naturally white and non-melaninated is now well established. The conditions favoring such growth are also known (Osborn, 1939, 1940*a*, *b*, and *c*) although many details await further investigations. The experimental requirements are two-fold: (1) That the surface in question must receive light either directly or by reflection and (2) that the physiological condition (nervous and hormonal factors) of the fish must be such that the internal environment of the normally pigmented cells favors dispersion [5] of the melanin granules (physiological darkening). Odiorne (1937) concluded that this condition also favored the slower morphological darkening in *Fundulus*. Similar findings have been reported in the lower vertebrates by Vilter (1931), Sumner and Wells (1933), Sumner and Fox (1935), Sumner and Doudoroff (1937), Sumner (1939, 1940*a* and *b*), Osborn (1939 and 1940*c*), and Dawes (1941).

The possible source of experimentally developed melanophores attracted the attention of Cunningham (1893), who saw no pigment migrating from the upper surface and so from negative evidence concluded the cells developed *in situ*.

The positive evidence presented here although partly circumstantial supports the view that these melanophores develop where they are first observed. The evidence gained from the direct observation (using both transmitted and reflected light) of small cells whose appearance and distribution agree in general with the picture seen in positive "Dopa" preparations requires no further comment. Likewise the observations concerned with the melanination of regenerated scales strongly favor

[5] That the degree of dispersion need not be maximal is shown by the fact that considerable ventral pigment may be grown on an animal whose dorsal surface is intermediate in shade. It is important to emphasize that the fish should not be in the pale phase.

the *in situ* origin of these melanophores. Furthermore, the fact that evidence gained in using the "Dopa" reaction as an indicator fits well into the other findings suggests that in this instance the reaction is significant and reliable. It is fully appreciated, however, that a positive "Dopa" reaction because of its non-specificity may in itself be of limited value or may prove to be misleading unless supported by evidence from other sources. In these experiments the "Dopa" reaction was used only to test for the presence of positive cells, thus avoiding the necessity of interpreting the implications of the chemical reaction. Because this problem is highly controversial at present some further discussion may be appropriate. That the positive "Dopa" test need not necessarily indicate the presence of a specific oxidizing enzyme ("dopa" oxidase) in the cell has been suggested by Figge (1940), who found that "Dopa" would react with other substances under test tube conditions to produce a black deposit. However, a characteristic feature of a melanoblast is that it contains some substance which will cause "Dopa" to react, forming a black material. This may be formed by a substance which oxidizes the "Dopa" or which acts as a redox substance to accelerate the auto-oxidation of "Dopa" in the absence of an enzyme. This latter possibility seems rather unlikely.

Another possibility is that the cells believed to be melanoblasts on the ventral scales may contain tyrosinase which for some reason has failed to react with tyrosine to produce pigmentation. Figge (1940) suggested that a positive "Dopa" reaction might indicate the presence in a cell of tyrosinase whose oxidizing action was inhibited by a glutathione-like substance. Such substances are known to inhibit the action of tyrosinase on tyrosine but do not inhibit the action of tyrosinase on "Dopa" (Figge, 1940). Tyrosinase actually blackens "Dopa" faster than tyrosine. It is seen then, that the observations made can be explained on a theoretical basis, although we do not, of course, know precisely what happens in the cell.

The question may be asked: "If the melanoblasts are present on the ventral surface, why do they not finish differentiation normally by manufacturing pigment?" It has been demonstrated that they do differentiate to true melanin-containing melanophores when the proper conditions are supplied. One might argue that the internal environment is the same in the ventral cells as in the dorsal cells and that the external environment differs only with regard to the amount of light which normally reaches the upper and lower surfaces of the flounder respectively. If this assumption is true, the following speculation may be offered. Is it possible that in the potential melanophores of the ventral scales a

tyrosine-tyrosinase reaction is inhibited by a glutathione-like reducing agent in the absence of light and that exposure to light (experimentally) might remove the inhibiting effect of the reducing agent and allow the enzyme to oxidize the color substrate? That the above assumption is not entirely true, however, is suggested by other observations. The internal environments for the cells of the dorsal and ventral scales are presumably alike in their hormonal constituents but not necessarily so in regard to their respective innervations. This is not known. Pouchet (1876) suggested, however, that a partial atrophy of the sympathetic system may accompany the migration of the corresponding eye during metamorphosis. In view of the present findings concerning ventral pigmentation, further experiments designed to provide new information on the possibility of the degeneration of sympathetic fibers to the ventral surface are needed.

Summary

Melanophores differentiate on the normally non-melaninated ventral surface of summer flounders when two conditions are satisfied. (1) The surface must be exposed to some light source when (2) the animal is in a physiological condition favoring darkening as witnessed by the behavior of the dorsal melanophores.

The melanophores develop "*in situ*" from potential melanophores (melanoblasts) whose presence is evidenced by the positive "Dopa" reaction, by direct observations of various stages of differentiation using direct and reflected light, by studies on regenerating scales, and by additional physiological data.

Theoretical considerations of the possible reactions involved in the experimental development of ventral melanophores and speculations as to why they are normally absent from the ventral surface are presented.

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NOTES ON THE PHYTOPLANKTON ON GEORGES BANK IN 1940

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In earlier surveys of the phytoplankton of the Gulf of Maine (Bigelow, 1926; Gran, 1933; Braarud, 1934, Bigelow, Lillick, and Sears, 1940; Lillick, 1940) relatively few observations were made on Georges Bank, and the data obtained have not been sufficient to give an accurate picture of the development of the spring flowering in any part of this important bank region. Previous information did, however, suggest that although the spring growth is never as luxuriant on the bank as elsewhere in the gulf, the growth nevertheless continues comparatively rich there throughout the summer (Bigelow, Lillick, and Sears, 1940).

With the hope of learning whether our earlier surmises were correct, samples were collected on five cruises to Georges Bank in 1940, from the latter part of March to the end of June, as a part of the study of the productivity of Georges Bank undertaken by various members of the staff of the Woods Hole Oceanographic Institution (Clarke and Bumpus). These were obtained at certain key stations at the 1, 10, 30, 50, and 80-meter levels, where the depth permitted (Riley, 1941), and at the 1-meter level at certain intervening stations (Figures 54, 55), i. e., at 78 localities in all on the bank and 33 close to the latter but outside the 90-meter contour. These samples were treated in the same manner as those for 1933–1934 (Bigelow, Lillick, and Sears, 1940, p. 151), so that the results of the two surveys should be directly comparable.

In the absence of samples taken prior to mid-March, the data for 1940,[2] fail to give any information 1) of the winter population or 2) of the inception of the spring flowering. However, although we cannot set the precise date for the initiation of the diatom flowering in 1940, this was obviously approaching its height during the

[1] Contribution No. 299.

[2] The original records are on file at the Woods Hole Oceanographic Institution.

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TABLE I—Numbers of Diatom Cells Within the 90-Meter Contour on Georges Bank in 1940

Date	Number of stations	Average number per liter	Number of diatom cells as estimated under 0.1 sq. meter of sea surface		
			Average	Maximum	Minimum
March 21–April 1	9	235,000	$1,432 \times 10^6$	$3,195 \times 10^6$	114×10^6
April 17–27	11	432,000	$2,078 \times 10^6$	$11,175 \times 10^6$	106×10^6
May 9–16	10	95,800	669×10^6	$2,629 \times 10^6$	68×10^6
June 1–8	25	19,800	328×10^6	$5,350 \times 10^6$	0
June 19–27	23	17,700	107×10^6	$1,217 \times 10^6$	0

latter part of March (Table I, Figure 54). And it reached its climax sometime about mid-April (Table I, Figure 55), for within the next two weeks, the population had decreased to approximately 1/3 its April value (Table I, Figure 55), continuing to decline to about 1/6 of the peak value by the first week in June and to about 1/20 by the latter part of June (Table I, Figure 55), when the observations were discontinued. In short, we have evidence of an active flowering continuing on Georges Bank for a month, followed by a period of nine weeks—perhaps more—when production was at least moderately active.

Indeed, Georges Bank may yet prove to be among the most productive areas in the Gulf of Maine when we compare diatom counts for the various regions. According to the most recent consideration of this question (Bigelow, Lillick, and Sears, 1940), it is not unusual to find diatoms so thick at the peak of their production that several billion may exist under 0.1 sq. meters of sea surface. However, in most localities this condition persists for a relatively short time and is followed by a period of extreme poverty. For example, the deep offshore stations of the Gulf, which yielded over 3 billion cells "per column" (Bigelow, Lillick, and Sears, 1940, p. 161, Figure 2) in April 1934, became relatively barren within the next month, the population having dwindled to 1/4000 of that existing in April. And even in close proximity to the bank, this same sequence was repeated in 1940, the population being about 1/1000 as great in early June as during the latter part of April[1] (Table II, Figure 55). On the bank, on the contrary, as also in Passamoquoddy Bay, a moderately rich population may persist for several months after the peak of the spring flowering, i. e., we may expect the popula-

[1] The numbers for the immediate vicinity of the bank are perhaps higher than those to be expected in the open basins of the gulf as there is probably some tendency at certain seasons for diatoms to be carried off the bank by the currents, particularly along the southern edge (Bigelow, 1927; Walford, 1938).

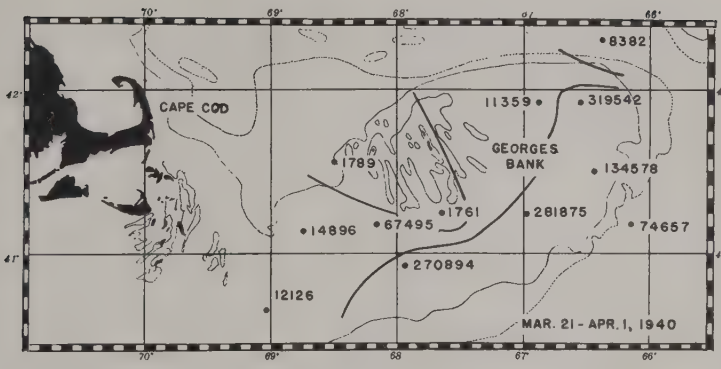

Figure 54. Chart of Georges Bank with numbers of diatom cells in tens of thousands per 0.1 square meter of sea surface. Contours delimit rich and poor areas.

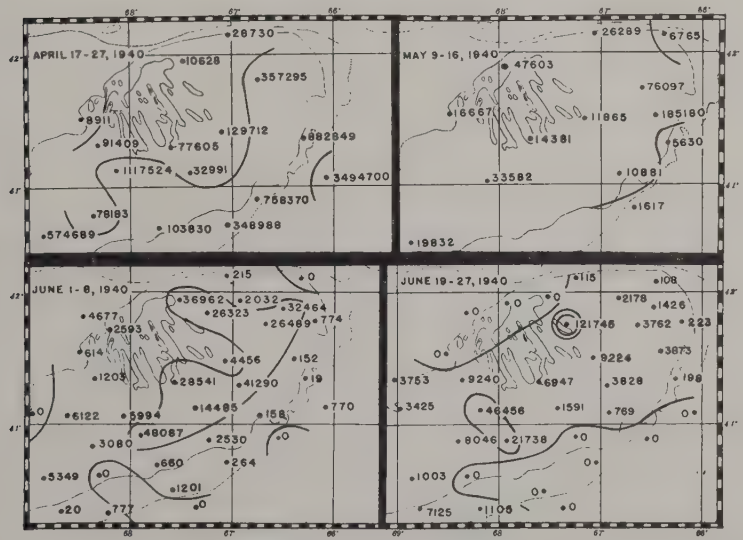

Figure 55. Chart of Georges Bank with numbers of diatom cells in tens of thousands per 0.1 square meter of sea surface. Contours delimit rich and poor areas.

TABLE II—Estimated Numbers of Diatom Cells Outside the 90-Meter Contour of Georges Bank in 1940

Date	Number of stations	Average number per liter	Number of diatom cells as estimated under 0.1 sq. meters of sea surface		
			Average	Maximum	Minimum
Mar. 21–Apr. 1	3	37,950	283×10^6	747×10^6	18×10^6
April 17–27	5	1,250,000	$10{,}988 \times 10^6$	$34{,}947 \times 10^6$	89×10^6
May 9–16	3	10,600	80×10^6	$2{,}629 \times 10^6$	16×10^6
June 1–8	11	1,010	8×10^6	47×10^6	0
June 19–27	11	1,480	12×10^6	38×10^6	0

tion in these localities to average several hundred million cells under each 0.1 sq. meter of sea surface rather than in the thousands. Thus, on the bank, where the counts averaged 2 billion cells at the climax of the flowering (in 1940), the average in late June was still about 107 million or 1/20 the "peak" value. Similarly, in Passamoquoddy Bay, where there is a record (in 1932) of 4 billion "cells per column" at the height of the flowering toward the end of April, in the subsequent period toward the end of June, 600 million cells were found (Bigelow, Lillick, and Sears, 1940, pp. 158, 162, calculated from Gran and Braarud, 1935; see also, Davidson, 1934).

It appears, then, from our survey of Georges Bank in 1940 that the bank is likely to prove to be as productive of phytoplankton as the Fundian region, especially as the scattered observations on the bank in the latter part of the summer show that rich growths regularly occur there at that time (Gran, 1933; Braarud, 1934).

While our 1940 survey shows the bank to be one of the more productive parts of the gulf in the numbers of diatom cells produced per annum, this does not actually answer the important question of whether its productivity in terms of "vegetable matter" is greater than in other parts of the gulf. Indeed, this is a very complex estimate to make, for not only are there differences in the size of the cells of various diatom species and variations in the size of the cells of any given species at different stages in its annual cycle, but also very little is known of their synthetic processes. One index of synthesis used in the survey on the bank is the chlorophyll content of water samples (Riley, 1941), but because there are no corresponding measurements elsewhere in the gulf, we must rely entirely on available information as to the numerical distribution of the species concerned for our estimates of productivity.

On Georges Bank it is doubtful whether Thalassiosira which initiates the spring flowering in most parts of the gulf, is ever as abundant as elsewhere in the gulf (Lillick, 1940, p. 206). Our samples taken the latter part of March support the earlier evidence

in this respect, for the water was dominated by various species of Chaetoceros, especially *Ch. decipiens* and *Ch. debilis* (Table III, Figure 56). These two species were well distributed over the bank, but with some tendency to concentrate over the southeastern half (Figure 57).

Indeed the species, *Ch. debilis* and *Ch. decipiens*, continued to dominate the flora numerically through April and to be as generally

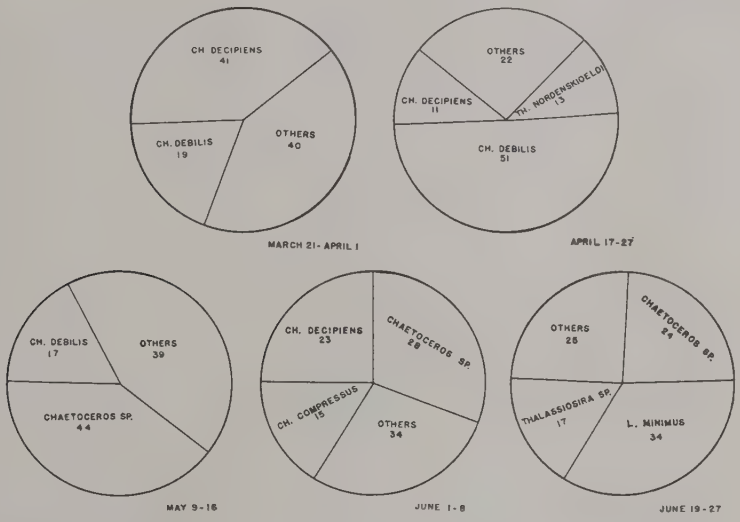

Figure 56. Average percentage composition of the diatom samples taken on Georges Bank.

distributed over the bank (Table III, Figures 56, 57). At the time of the April survey, however, *Thalassiosira Nordenskioeldi* had so increased in abundance that it formed roughly 13% of the total population (as compared with 3% in late March, Table III). It was somewhat more densely distributed over the southeastern portion of the bank, but actually it was thickest outside the 90-meter contour (Figure 58),—presumably having been carried off the bank by the drift of the water (Bigelow, 1927; Walford, 1938).

By mid-May, however, not only had the population of *Th. Nordenskioeldi* again dwindled (now 3% of the total), but also that of both *Ch. decipiens* and *Ch. debilis*. These were almost entirely confined to the bank itself (Figure 57). With the diminution of these

TABLE III—Average Numbers of Diatom Cells per Liter on Each of the Cruises to Georges Bank During 1940[1]

Species	*March*	*April*	*May*	*June 1–8*	*June 19–27*
Asterionella japonica	580	2879	1492	90	X
Chaetoceros atlanticus	2365	4273	1360	360	135
Chaetoceros borealis	3323	4150	689	254	23
Chaetoceros compressus	3983	9172	6888	2904	468
Chaetoceros constrictus	X	90	121	771	1310
Chaetoceros debilis	45238	221517	16686	308	—
Chaetoceros decipiens	95706	46310	5083	4667	791
Chaetoceros laciniosus	X	X	7744	1707	393
Chaetoceros sp.	1720	9129	19569	2212	1249
Chaetoceros spores	X	140	1144	692	665
Coscinodiscus sp.	1359	689	271	172	41
Coscinosira polychorda	419	2391	1139	98	162
Fragillaria sp.	X	X	106	746	X
Guinardia flaccida	X	679	95	X	100
Leptocylindrus danicus	X	25	X	X	204
Leptocylindrus minimus	X	38	X	X	5993
Melosira sulcata	595	1187	12	285	307
Navicula sp.	X	235	257	1376	236
Nitzschia seriata	2492	1143	1779	407	591
Rhizosolenia fragilissima	X	1328	1009	X	89
Rhizosolenia hebatata semispina	249	721	4200	401	20
Thalassionema nitzschioides	1058	1198	324	203	28
Thalassiosira decipiens	3097	11659	2629	466	—
Thalassiosira gravida	805	47	10	1025	242
Thalassiosira hyalina	X	6291	X	X	X
Thalassiosira Nordenskioeldi	7189	55280	3177	119	110
Thalassiosira sp	98	3825	239	715	2933

[1] X signifies that the species was detected in quantities averaging less than 1 cell per liter while — signifies that the species was not detected on that particular survey.

forms, another Chaetoceros species, *Ch. compressus*, appeared in some abundance over the northeastern portion of the bank (Figure 58).

By early June, the center of abundance for *Ch. compressus* had shifted somewhat to the west and south. And on this survey, with a closer network of stations, it is more obvious that the reduced population of *Ch. decipiens* was chiefly confined to the bank (Figure 58).

By the latter part of June—when the surveys were discontinued—this species was definitely limited to the central part of the bank and the numbers remained comparatively small—only enough to make 4% of the reduced population (Table III, Figure 57). But at this time, *Leptocylindrus minimus* and a small species of Thalassiosira (of doubtful identity) were taken relatively abundantly in roughly this same area (Figures 56, 58).

With this survey of the chief species concerned in the diatom production on Georges Bank, it seemed desirable to justify our contention that the bank is one of the more productive areas (as appears

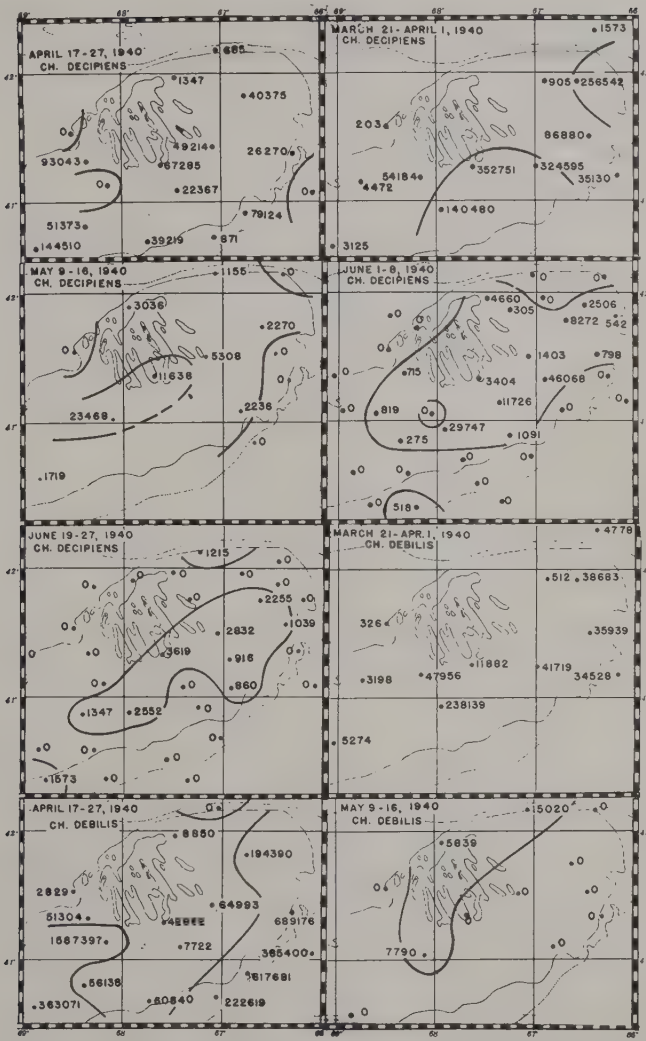

Figure 57. Chart of Georges Bank with average numbers of representative diatom cells per liter.

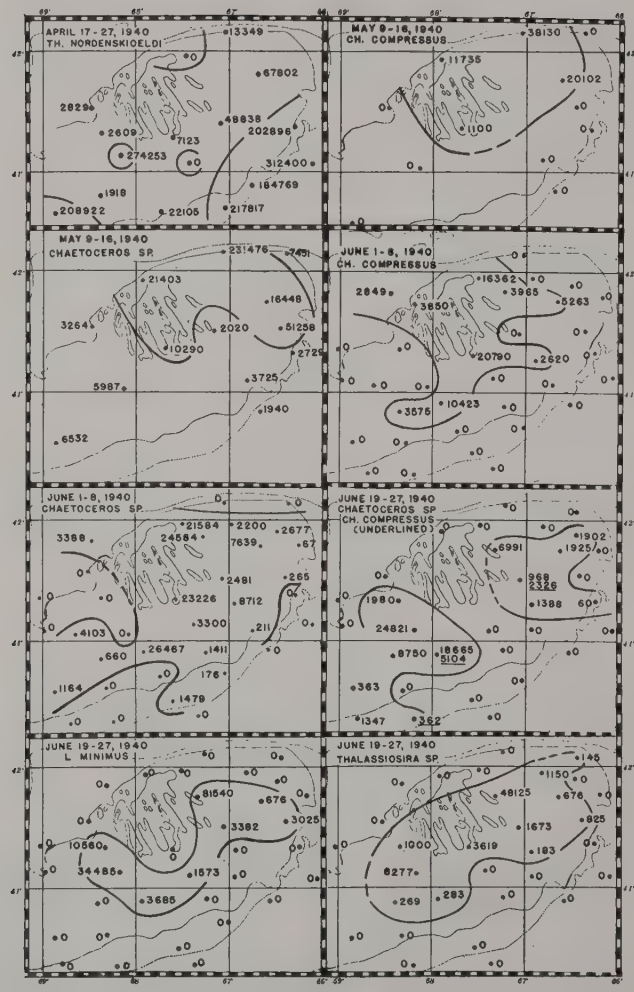

Figure 58. Chart of Georges Bank with average numbers of representative diatom cells per liter.

from a consideration of numbers alone) by a consideration of their bulk,[1] because of the great differences in the size of the species occurring on the bank. Thus, it is obvious that *Chaetoceros decipiens*[2] is many times the bulk of *Leptocylindrus minimus*[3]—I estimate *roughly* 200 times. This would mean that when *Ch. decipiens* dominated the flora toward the peak of the flowering, the organic matter produced by this species alone would perhaps be 3000 times greater than that produced by *L. minimus* when it dominated the plankton toward the end of June—that is, if we are justified in assuming that the production of organic matter by a species is directly proportional to its volume. However, when we consider the bulk of all the more abundant species, it appears that the sizes are so varied at all times that the relative volumes of diatoms do not vary markedly from the relative numbers of diatom cells taken on each cruise (Table IV). Hence we are probably justified in concluding that Georges Bank is among the more productive areas of the gulf.

TABLE IV—Comparison of Relative Volumes[1] and Relative Numbers of Diatom Cells Estimated for each Cruise

Date	*Relative volumes*	*Relative numbers*
March 21–April 1	30	13
April 17–27	28	19
May 9–16	3.9	6
June 1–8	4.4	3
June 19–27	1	1

[1] Estimated from the dimensions given in Gran (1908) and Hustedt (1930) and from Tables I and III.

SUMMARY

The 1940 phytoplankton survey on Georges Bank shows not only that a spring increase takes place but that there is a more prolonged period of diatom abundance than in most parts of the gulf. Furthermore, at the peak of production, the waters surrounding the bank, particularly to the southeast are as rich, if not richer, than the waters on the bank, but later these waters become practically devoid of diatoms (Tables I–II, Figures 54–55).

[1] The volume of a diatom cell may be very roughly calculated from the dimensions given in Gran (1908) or Hustedt (1930).

[2] 12–78 μ wide and perhaps ½ as long (Gran, 1908, p. 74).

[3] 1.5–2.5 μ wide and 40 μ long (Hustedt, 1930, p. 561).

Chaetoceros seems to be the most characteristic genus throughout the spring—a large species, *Ch. decipiens*, being characteristic of the early part of the season and smaller species such as *Ch. debilis*, *Ch. compressus*, etc., during the latter part of the season, with an exceedingly small species, *Leptocylindrus minimus*, forming as much as 34% by number by late June (Table III, Figure 56).

Taking the size of the species concerned into consideration strengthens the idea that the period of maximum production of "vegetable matter" took place between late March and late April, although the production continued moderate through late June (Table IV). It further indicates that Georges Bank is one of the more productive areas of the gulf.

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Contribution No. 300

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A COMPARATIVE STUDY OF THE EFFECTS OF IONS ON WHOLE NERVE AND ISOLATED SINGLE NERVE FIBER PREPARATIONS OF CRUSTACEAN NEUROMUSCULAR SYSTEMS*

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Society of Fellows, Harvard University, Cambridge, Massachusetts

EIGHT FIGURES

INTRODUCTION

The study of crustacean neuromuscular systems is not a new one; a large body of data referent to this subject is already at hand. Qualitatively many peculiar characteristics have been described in the peripheral parts of these systems: specific inhibitory neurones, facilitation of at least two types, multiple motor innervation, and the like (for review, see Wiersma, '41, p. 264 ff.).

Considerable interest centers about these properties not only in relation to crustacean behavior but also for possible clues to the mechanisms of summation, inhibition, and other similar functions of the vertebrate central nervous system. Furthermore, recent evidence suggests that even in vertebrate skeletal muscle innervation some of these properties of crustacean systems such as multiple motor innervation do occur in more complex form (see for example, Häggqvist, '38; Katz and Kuffler, '41). However, little quantative data is available, and the problems involved in neuromuscular transmission in Crustacea remain almost untouched.

One of the approaches to this field which seemed most promising was through a study of the action of ions, drugs, and other substances on such effector systems. The experiments described in the present paper are limited to a description of the effects of various ions, especially potassium, on the peripheral neuromuscular system of three decapod crustaceans: the Bermuda spiny lobster, Panulirus argus (Latreille), the European spider crab, Maia squinado Latreille, and the southern crayfish, Cambarus clarkii Gerard.[1]

* Contribution No. 300 of Woods Hole Oceanographic Institution.

[1] I am deeply indebted to the directors and staffs of the Bermuda Biological Station, the Marine Biological Laboratory at Plymouth, England, and the Biological Laboratories of the California Institute of Technology, where various parts of this work were carried out. My thanks are also due especially to Dr. John H. Welsh, Dr. C. F. A. Pantin, and Dr. C. A. G. Wiersma for many suggestions and helpful advice generously given in the course of these experiments.

Some previous work of this sort has already been done, but the conclusions which may be drawn from the available data are sharply limited. This limitation is due, at least in part, to lack of sufficient attention to the problem of perfusion. In all the present experiments, a continuous rapid stream of physiological salt solution was made to pass over the neuromuscular system being studied,[2] while stimulation was effected by regular bursts of condenser discharges or faradic impulses applied to the nerve.

A second difficulty with most previous work was that the stimulation was not sufficiently controlled. It is important in view of the multiple innervation of crustacean skeletal muscle to know just which of the motor and inhibitory fibers are activated by the stimulation. This is usually impossible when an intact nerve is used. In the present paper a comparison is made between the effects obtained by stimulating isolated single nerve fibers and by stimulating whole leg nerves. This comparison is especially interesting with respect to excess potassium in the perfusion fluid, which was found to affect the fast and slow neuromuscular systems in quite opposite ways, a fact which is helpful in understanding some of the "anomalous" results which have been obtained with whole nerve stimulation.

METHODS

I. Panulirus. Whole walking legs were cut off at the autotomizing joint and prepared for the experiment by removing the shell of the dorsal surface of the propodite (the penultimate segment), and the extensor muscle of the dactylopodite (terminal segment) was excised. Then the leg was so attached that excursions of the dactyl due to changes in the length of the flexor dactyl muscle would be isometrically recorded on a smoked drum.

Two small holes were bored in the shell of the meropodite to admit the platinum wire stimulating electrodes which were inserted so that the leg nerve was stimulated by them. Trains of electrical stimuli were applied to the preparation by this means at regular time intervals. These stimuli were discharges from a 0.1 μF condenser charged by a 240 volt EMF source and discharging through a gas triode (RCA 885) and a resistance of 10,000Ω in series with it.[3] This resistance was used as a potentiometer from which to tap off the stimulating current.

[2] Unfortunately, in preliminary trials perfusion through the normal circulatory channels was found to be impractical.

[3] My thanks are due to Dr. C. Ladd Prosser who suggested the general circuit of this oscillator and to Dr. Morgan Upton who built it.

The frequency of discharge could be varied from 5 to 125 shocks per second, and the impulses so obtained were sent into the leg nerve for 1 second out of every 15.

A satisfactory method of obtaining a fairly rapid perfusion (the decapod circulatory system gives the impression of being a low pressure high speed circuit) was through a glass cannula inserted into the carpopodite (antepenultimate segment of the leg). Most of the perfusate flowed distally from the point of introduction and thence out through the opening cut in the propodite. Thus the flexor dactyl and the parts of the leg nerve near it were bathed in quite rapidly circulating perfusion fluid.

In order to maintain a reasonably constant rate of continuous perfusion a series of Mariotte bottles was so arranged as to provide a steady perfusion pressure and permit changes in the perfusion fluid to be made without markedly affecting its rate of flow. The speed of perfusion averaged about 15 cm.^{3}/minute.

The basic perfusion fluid used contained 30.7 gm. NaCl, 0.975 gm. KCl, 1.56 gm. $CaCl_2$, and 0.78 gm. $MgCl_2$ per liter. This was the same formula as that given by Pantin ('34, p. 14) except that the concentration of Mg^{++} was reduced to one-third in order to increase the size of the contractile response. Since the preparation was found to be sensitive to any considerable changes in the pH of the perfusion fluid, the solutions were brought to a pH of about 7.0 with $NaHCO_3$ (which would also afford a slight buffering action).

No thermo-regulation was attempted during the experiments, but the slow drifts in the laboratory temperature were of such a magnitude (1–2°C. changes over several hours) as to preclude their influencing any one experiment significantly.

II. Maia. The method of preparing the legs of this crab for the experiments differed from that used for Panulirus in several respects. The leg to be studied was left intact on the animal and a ventral dissection was made (as shown in fig. 1) to expose the ventral ganglionic mass and the proximal portions of the leg nerves. The stimulating electrodes were placed under the appropriate leg nerve, which had been cut centrally to isolate it from the rest of the nervous system. The details of perfusion and stimulation were the same as in Panulirus.

III. Cambarus. Non-regenerated claws of the crayfish were used. The leg was removed from the animal and isolated single nerve fibers were prepared in the meropodite according to the technique of van Harreveld and Wiersma ('36, pp. 87–88). Stimulation in the form of faradic shocks was supplied every 15 seconds either as single break shocks, which

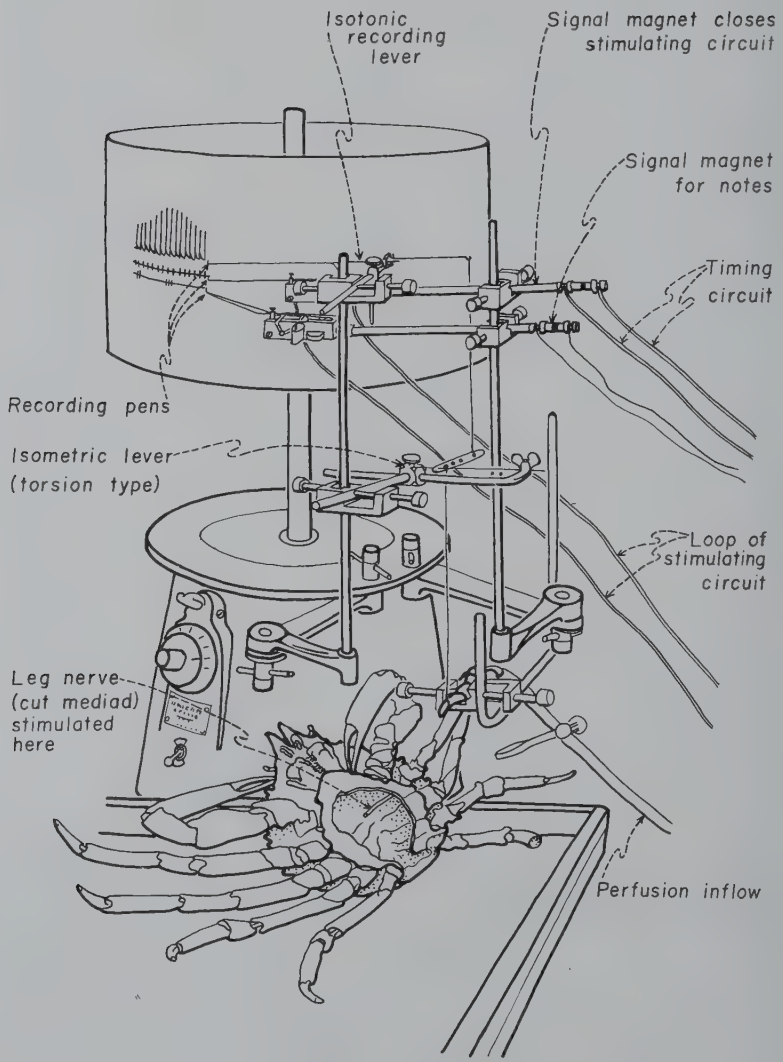

Fig. 1 Maia. Method of exposing leg nerve and arrangements for recording isometric contractions of the corresponding perfused flexor dactyl muscle of a walking leg.

would evoke a sharp contraction when applied to the isolated nerve fiber of the fast system of the claw closer muscle and no response from any other (Wiersma and van Harreveld, '38, p. 75), or as 1 second bursts of make and break shocks, which were always used to stimulate the nerve fiber of the slow closer system and sometimes that of the fast. The general perfusion technique was similar to that described above except that the perfusate flowed from its point of introduction at the tip of the propodite centrad through the leg to the open section of the meropodite.

The basic perfusion fluid used in all the experiments on Cambarus was that described by van Harreveld ('36) and contained 12.0 gm. NaCl, 1.5 gm. $CaCl_2$, 0.4 gm. KCl, 0.25 gm. $MgCl_2$, and 0.20 gm. $NaHCO_3$ (which must be added last to prevent calcium precipitation) per liter.

RESULTS

I. Panulirus

A. Potassium. In the spiny lobster the amplitude of the contraction of the perfused flexor dactyl muscle responding to the standard burst of stimuli given to it via its nerve varied inversely with the amount of K^+ present in the perfusion fluid (fig. 2A). The presence of three to four times the usual concentration of this ion in the perfusate was sufficient to cause contraction amplitude to decrease to zero. Increase in the amount of potassium above normal was followed also by a rise in the base line of the contractions; the tension reached in this rise with very high K^+ concentrations might be severalfold that developed by the contraction itself during normal perfusion.

Occasionally at the beginning of an experiment 2 K,[4] instead of decreasing the twitch tension as usual, caused it to increase markedly.

B. Magnesium. The higher the concentration of the magnesium ion in the perfusate the smaller was the size of the mechanical response to nerve stimulation. This relation was found to hold both above and below the level of Mg^{++} present in the normal perfusion fluid. No changes in the position of the base line occurred with the various amounts of Mg^{++} tested (fig. 2B).

C. Calcium. Reducing the amounts of Ca^{++} present in the perfusate made the responses of the preparation irregular and frequently resulted in a decrease in contraction amplitude and the development of an irregular base line rise of large size. Two to three times the normal

[4] The "2 K" refers to perfusion fluid which was normal except that twice the usual amount of potassium was present; similar abbreviations are used for other altered perfusion fluids.

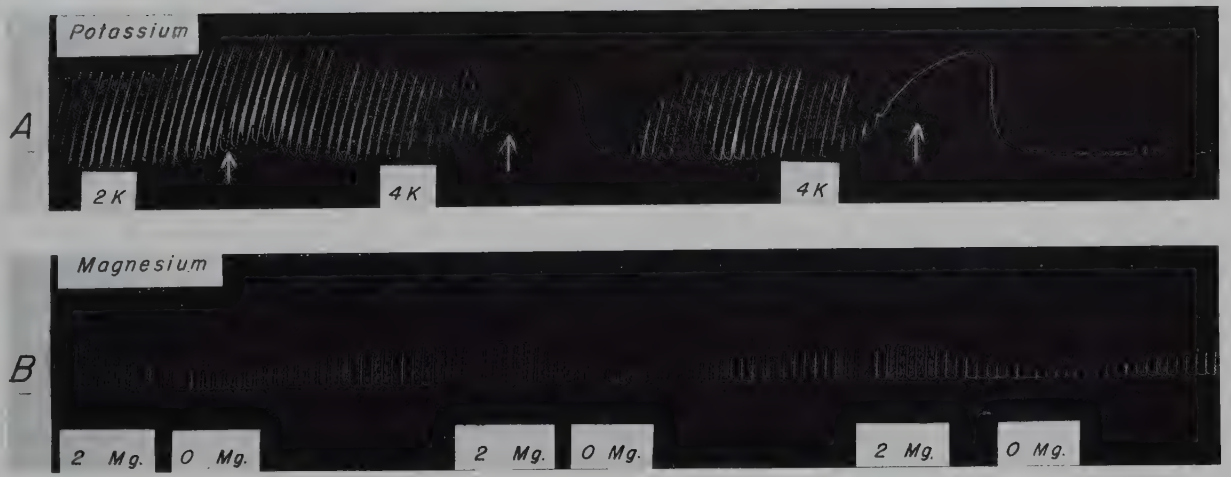

Fig. 2 Panulirus. A. Effects of excess potassium on contractions of the flexor dactyl of a walking leg. One second bursts of condenser discharges were applied to the whole nerve every 15 seconds. Isometric recording. B. Similar record showing effects of changing the amount of magnesium in the perfusion fluid. In A the arrows indicate where normal perfusion was resumed. In B the breaks in the series of contractions show when the perfusion fluid was changed.

concentration of this ion sometimes, but not always, caused an increase in the size of the contractile response.

II. Maia

A. Potassium. In the great majority of cases in a long series of experiments any increase in the amount of this ion present in the perfusate was followed by a decrease in the size of the contraction and a rise in base line (figs. 3A and 3B). Even 1.3 K caused perceptible changes in these directions. When the concentration of K^+ reached four to five times the normal concentrations, the contractions disappeared altogether, and the resting tension (base line) rose to about

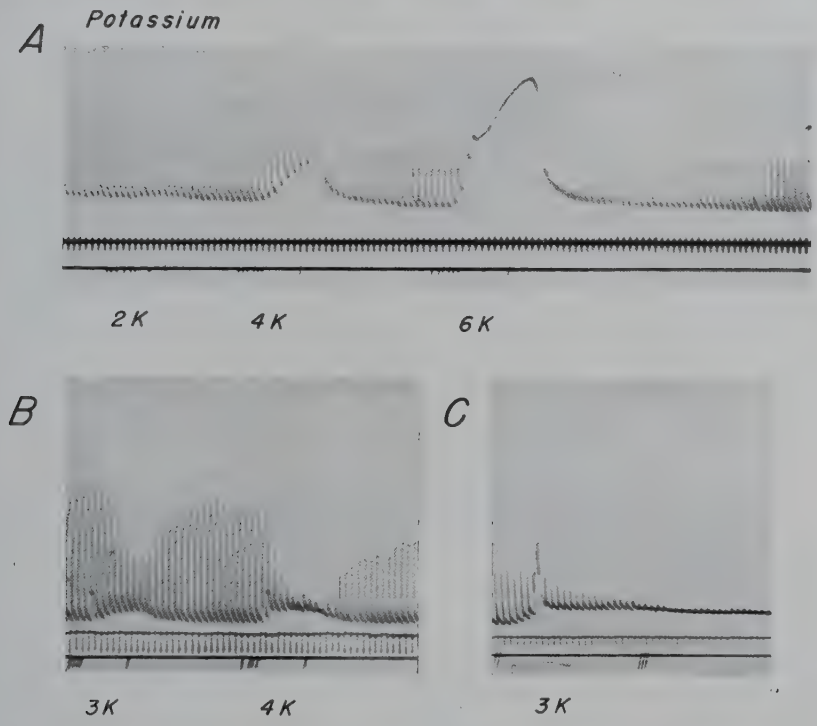

Fig. 3 Maia. Effects of excess potassium on isometric tension developed by the flexor dactyl of a walking leg in response to 1 second bursts of condenser discharges given every 15 seconds to the intact leg nerve. On the kymograph records marks on the line directly below the myogram indicate when the nerve was stimulated. The lowest line shows when the perfusion was changed: the single marks indicate when normal perfusion began; the groups of marks show when the various altered perfusion fluids were circulated. In A and B the typical potassium effects are shown while in C one of the less usual effects described in the text appears.

50% of that reached in the normal contraction. Greater rises in base line resulted from still larger amounts of K^+. Amplitude recovery after such high concentrations was very slow and incomplete. The base line returned to its original level considerably before contractions began to reappear on return to normal perfusion.

While the above results were those generally found, in a small number of significant cases quite different effects from these were observed. In these cases instead of causing an amplitude decrease, increased K^+ in the perfusate brought about an increase in amplitude. This was especially notable when the various perfusion solutions were all cooled to about 10 to 12°C. Occasionally with high potassium concentrations (three to thirty times normal were tried) a very large contraction, two or three times the size of the preceding ones would appear when the

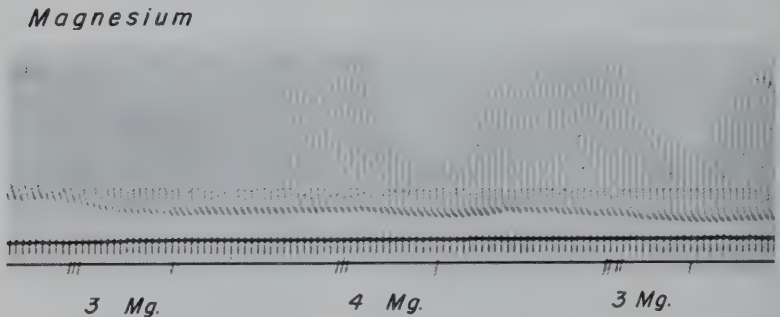

Fig. 4 Maia. Effects of various concentrations of magnesium on response of the flexor dactyl. Record obtained as described in figures 1 and 3.

altered perfusion fluid reached the preparation, but thereafter no further contractions occurred although the usual rise in base line took place (fig. 3C).

B. Magnesium. The size of the mechanical response of the flexor dactyl to stimulation of the whole leg nerve was found to vary inversely with the amount of Mg^{++} present in the perfusate, being largest when none of this ion was present. Three times the amount of this ion used in the standard perfusion fluid caused a decrease in amplitude which varied from 12 to 60% in different trials made in the course of a large number of experiments (fig. 4).

C. Calcium. An increase in the amount of Ca^{++} present in the perfusion fluid up to three times the normal amount resulted in an increase in the amplitude of the contractile response but no change in the base

line (fig. 5B). Ca^{++} concentrations greater than three times normal brought about decreases in contraction amplitude (70% with 14.5 Ca) but no base line changes. It was noteworthy that even with such very high concentrations recovery of the preparation was good (fig. 5A).

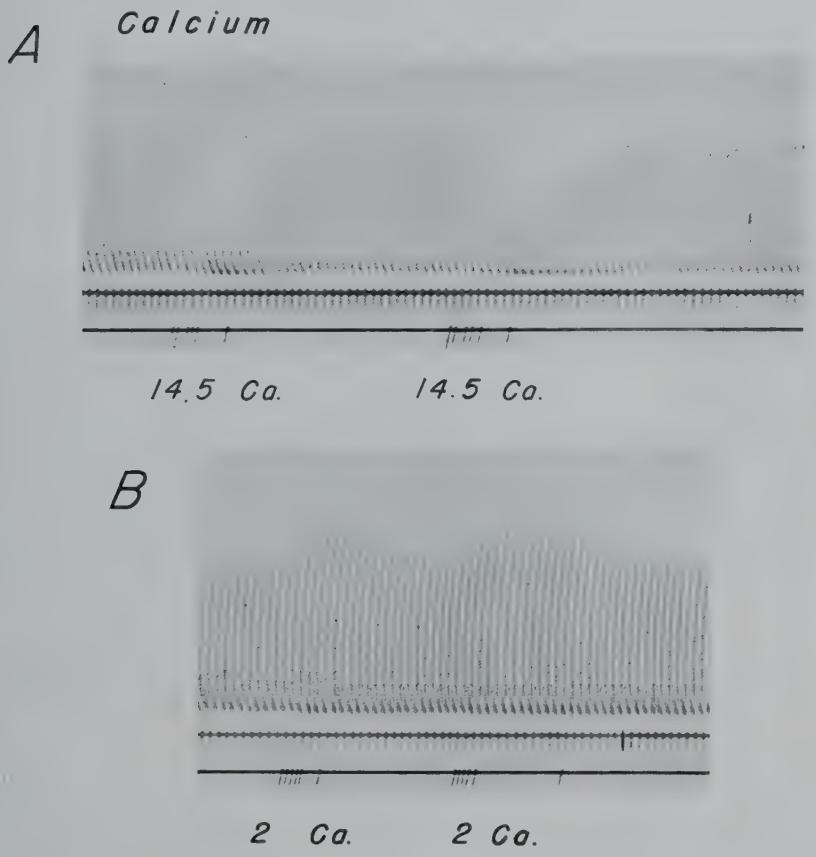

Fig. 5 Maia. Effects of various concentrations of calcium on response of the flexor dactyl. Record obtained as described in figures 1 and 3.

III. Cambarus

A. Potassium.

1. Fast closer motor fiber. Even small changes in the amount of K^+ in the perfusion fluid had marked effects on the mechanical responses of the claw closer muscle to fast fiber stimulation with single or repetitive shocks. Within certain limits the tension developed by the twitch was proportional to the amount of K^+ perfused (fig. 6).

A decrease from the normal in the concentration of this ion was followed by a reduction in the amplitude of contraction; an increase, even to as little as 1.5 times the normal amount, caused a sharp rise in the size of the twitch. When the concentration of K^+ was increased to four times that present in van Harreveld's solution, the resulting amplitude rise was sometimes followed by a fall in twitch tension. Still larger amounts of K^+ caused a failure of response to fast fiber stimulation; recovery from such high concentrations of this ion was slow and often incomplete.

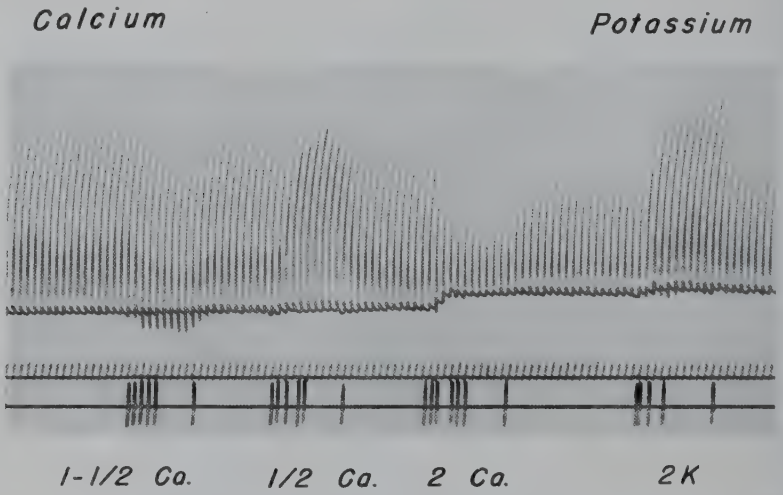

Fig. 6 Cambarus. Effects of calcium and potassium on the response of the fast closer system of the claw. The isolated single nerve fiber was stimulated by a faradic break shock once every 15 seconds. Isometric recording.

With greater than normal concentrations of K^+ in the perfusion fluid the base line of the contractions rose by amounts roughly proportional to these concentrations. (The base line returned to its original level during recovery more rapidly than the size of the contraction.)

2. Slow closer motor fiber. The mechanical response evoked in the claw closer muscle by slow fiber stimulation was less sensitive to changes in the K^+ content of the perfusion fluid than was that of the fast twitch. Furthermore, increasing the amount of K^+ never increased the amount of tension developed by the slow contraction. On the contrary, with two times or more the normal concentration of K^+ the amplitude of the mechanical response decreased; to zero when this amount was four to five times or more the usual amount in crayfish blood (fig. 7A).

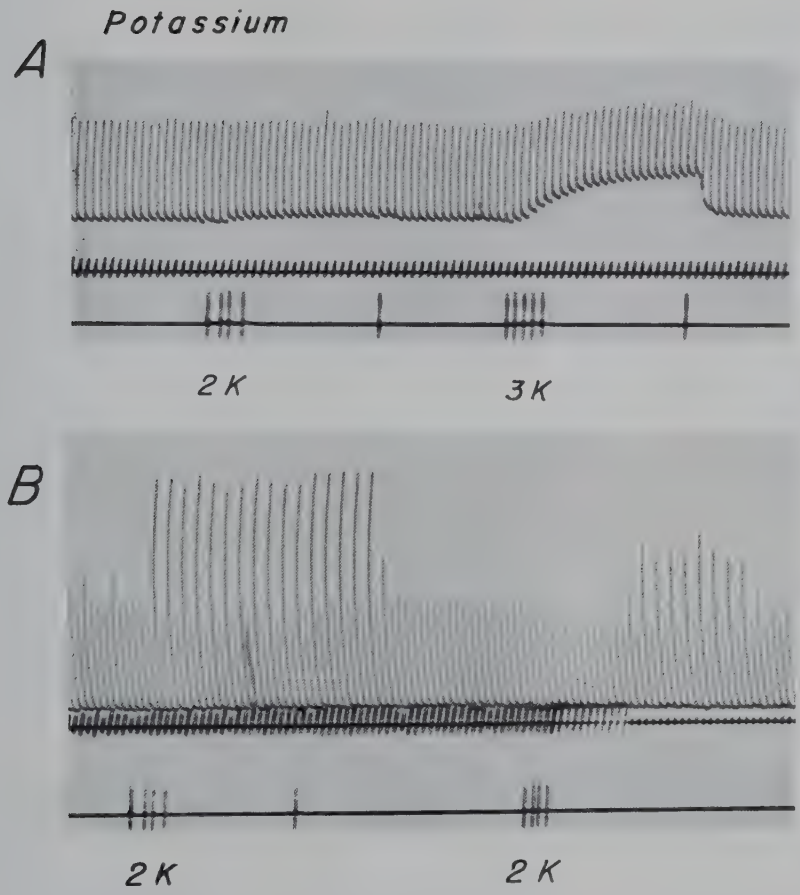

Fig. 7 Cambarus. Effects of potassium on the slow and fast contractions of the claw closer muscle. In A 1 second bursts of faradic impulses were given every 15 seconds to the isolated slow closer motor nerve fiber. In B both slow and fast motor fibers were isolated. Alternately single break shocks were given to the fast and 1 second volleys to the slow at 15 second intervals. The stronger contractions with increased K were the responses of the fast system. The fact that the responses of the muscle to single impulses in the fast nerve fiber and the responses to 1 second bursts of impulses in the slow nerve fiber were of the same size during normal perfusion on the record is only coincidental. At the beginning of an experiment with a fresh preparation the fast system response to a single shock is much larger than that of the slow to a full second of faradic stimulation, as shown in figure 8B, but the fast system fatigues much more rapidly than the slow. Hence, after passing through a condition like that shown in figure 7B, the fast contraction becomes smaller than the slow and finally stops altogether in response to a single shock while the slow contraction continues to develop only slightly less tension than before.

Increased perfused K^+ caused a rise in base line which with high concentrations (four to five times the amount present in van Harreveld's solution) sometimes considerably exceeded in tension that developed by the contractions during normal perfusion.

3. Fast and slow fibers together. The above effects of K^+ on responses to stimulation of the fast and slow fibers of the crayfish claw closer were found in separate experiments where only one or the other of the fibers was prepared and studied. Precisely comparable results were obtained in a series of experiments in which both slow and fast fibers to the same muscle could be independently stimulated. When such a preparation was alternately stimulated through the slow then the fast fiber, the difference in effect on the responses of changing the K^+ content of the perfusion fluid were clearly evident (fig. 7B).

In the few cases where fast and slow fibers were stimulated simultaneously an increase in perfusate K^+ to two or three times normal caused a decrease in the amplitude of the mechanical responses and a rise in base line.

B. Magnesium.

1. Fast closer motor fiber. Absence of Mg^{++} from the perfusion fluid caused about a 25% increase in the amplitude of the mechanical response. On the other hand a rise in the amount of Mg^{++} present was followed by a fall in the size of the twitch, e.g., 2 Mg resulted in about 10% amplitude decrease. Four to five times the normal concentration of Mg^{++} decreased the size of the response 50 to 75%, but sometimes recovery of contraction amplitude after as large amounts as these was slow and incomplete.

2. Slow closer motor fiber. The responses evoked by stimulation of the slow closer fiber were affected in a similar manner (fig. 8A). Some experiments were carried out to see whether magnesium had any effect on autofacilitation (Wiersma and van Harreveld, '39, p. 44) in the slow closer neuromuscular system. In these the facilitating effect which a 4 second faradic stimulation of the isolated nerve fiber had when it was interpolated in a series of 1 second faradic shocks given at regular intervals to the same isolated slow closer motor nerve fiber, was studied with normal perfusion and with excess magnesium. Excess magnesium as usual caused a decrease in the size of the contractile response but had no obvious effect on the facilitation produced by the interpolated tetanus on the succeeding regular contraction.

3. Fast and slow closers together. Alternating stimulation of fast and slow fibers in the same preparation showed the same results as those found separately (fig. 8B).

A series of trials using the same Mg^{++} concentrations as before but employing $Mg(NO_3)_2$ instead of $Mg(Cl)_2$ demonstrated that somewhat

greater decreases in amplitude were evoked with $Mg(NO_3)_2$ than those described above with $Mg(Cl)_2$.

Of the ions tried the most uniform results were obtained with magnesium in all the crustaceans studied; also it was noteworthy that recovery was about as fast as effect when concentrations of Mg^{++} not more than three times normal were used.

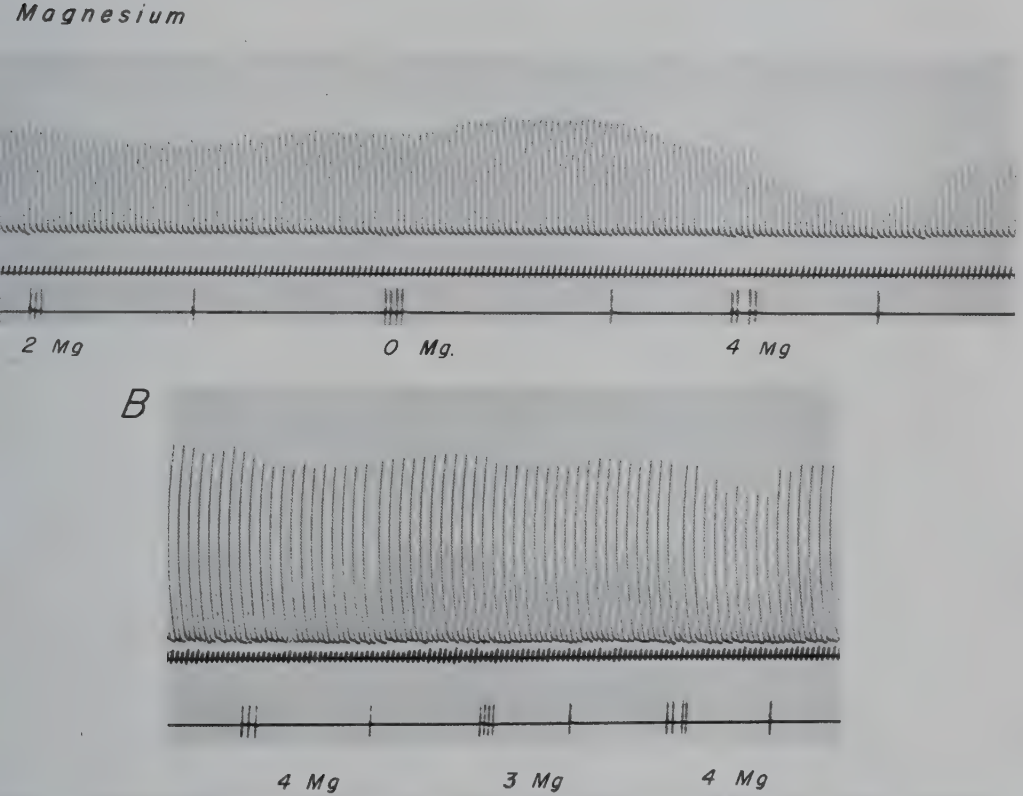

Fig. 8 Cambarus. Effects of magnesium on the slow and fast contractions of the claw closer muscle. Stimulation A was given to the isolated slow closer fiber in 1 second faradic volleys; in B both fast and slow closer rve fibers were isolated and alternately stimulated as in figure 7B. The stronger contractions are those of the st system. Isometric recording.

C. Calcium. Results obtained by varying the relative amounts of Ca^{++} present were quite irregular. However, decreasing the concentration of Ca^{++} to one-half that in the blood in several cases was followed by an increased response to fast fiber stimulation. In one case this increase in twitch tension was 100% of the original and was accompanied by some spontaneous contractions; at the same time the slow twitch disappeared. With two to three times normal Ca both slow and fast responses were generally decreased in amplitude, and twitches became irregular if such perfusion continued for many minutes.

DISCUSSION

I. Potassium. The most striking result of the present experiments was the difference in the effect of changing the amounts of this ion present in the perfusion on a whole nerve preparation and on a single fiber preparation. When the stimulating electrodes were in contact with the intact leg nerve, an increase in the amount of perfused potassium was followed by a decrease in the amplitude of the closer muscle's response. When a single motor fiber was being stimulated, a change in the potassium concentration resulted in quite opposite results depending on whether the nerve fiber in question was the "fast" or the "slow" closer fiber.

If it were the slow fiber (in Cambarus), the amplitude of contraction was inversely proportional (over a range from 0 K to 4 to 5 K) to the amount of perfused potassium exactly as it was generally found to be in whole nerve preparations (in Panulirus, Maia, and Cambarus). If it were the fast fiber (again in Cambarus), the contraction amplitude was directly proportional to the potassium concentration (from 0 K to 4 or more K).

These results show that certainly in the case of the crayfish and probably in the other Crustacea studied repetitive "stimulation" of the whole leg nerve gives rise to effects similar to those evoked by stimulation of the slow closer motor fiber alone. This is not surprising in view of the rapidity with which the fast closer fiber will fatigue when it is stimulated repetitively for any considerable time. Corroborative evidence is afforded by the occasional "anomalous" effects of excess potassium on whole nerve preparations described above for the spiny lobster and the spider crab. In these cases, increases, instead of the usual decreases in contraction tension, sometimes resulted from perfusion with fluid containing two to three times the normal amount of potassium. These unusual changes always occurred at the very beginning of experiments when the closer muscle response might be expected to be dominated by the as yet unfatigued fast neuromuscular system.

From the consideration of such results it is quite clear that stimulation of the whole crustacean leg nerve, evoking as it does an unknown number of impulses in the slow and fast motor fibers as well as in the inhibitory ones, will yield results which are quite unsatisfactory for most analytical purposes involving neuromuscular mechanisms (see Wiersma, '39, p. 249). Some method of controlling the number and frequency of the impulses which pass along the separate nerve fibers is essential in any experiment designed to avoid difficulties of this sort;

the Wiersma and van Harreveld technique for single nerve fiber isolation in these nerves provides such a method of control.

Do the preceding data shed any light on the processes of neuromuscular transmission in the Crustacea? An affirmative answer to this question would seem to be in order since evidence from previous work indicates that the present potassium effects must have their site of action somewhere in the neuromuscular transmission processes, that is somewhere in the sequence of events occurring between the arrival of the propagated nerve impulse at the myoneural junction and the development of the contractile response. This evidence consists of data which appear to exclude the site of action of the K^+ from other parts of the system, namely the nerve and the muscle. According to Cowan ('34) and Katz ('36), in whole walking leg nerves, and more recently, Marmont (personal communication, '40) in isolated single motor fibers, the only effects of excess potassium in crustacean nerve were the suppression of response to stimulation when concentrations of this ion higher than three to five times normal were present.[5] It is clear from this that the potassium effect on the fast neuromuscular system cannot be localized in the excitability or the action currents of the nerve fiber itself.

However, excess potassium has been found (Cowan, '34) to decrease the electrical response of the whole leg nerve of Maia; this effect could readily be explained to be a result of more and more of the nerve fibers becoming inexcitable as the potassium concentration increased causing the overall electrical response to become progressively smaller. Alternatively, it could be explained as depending on a decrease in the size of the individual nerve fiber action currents which would result in the same observed effect. If this second explanation is the correct one, the results found in the present studies might be explained on the basis of a decreased slow closer motor fiber action current since the all-or-none "law" by no means holds between nerve action current and contractile response in these systems (Wiersma and van Harreveld, '38, p. 80). Hence, other things being equal, a smaller nerve action current in a single fiber might give rise to a smaller contractile response.

On the other hand available evidence indicates that the present potassium effects with the probable exception of the sustained contractions caused by high K^+ concentrations could not be localized in the contractile mechanism. All data (anatomical: van Harreveld, '39, p. 281;

[5] Katz ('36, p. 214) described a brief burst of impulses in the whole leg nerve occurring in response to potassium concentrations ten to twenty times normal, but these data hardly seem pertinent to the present comparisons.

physiological: Wiersma and van Harreveld, '38, p. 80; and chemical: Bergren and Wiersma, '38) so far obtained suggest that the effector mechanisms are the same for the fast and slow contractions of crustacean muscle. Hence, in the present case excess potassium would be acting on some mechanism central to the contractile one.

Limiting the effects of the K ion largely to the process of neuromuscular transmission, does not reduce the problem to a simple one, however, since the transmission process itself is a very complex system (see, for instance, the schema proposed by Marmont and Wiersma, '38, p. 192, and Wiersma and van Harreveld, '39, fig. 5). Furthermore, the potassium ion is quite probably involved in a multitude of the various steps which make up this system.

Preliminary experiments designed to break down this complex situation to some extent by recording the muscle action potentials in perfused single fiber preparations of the Cambarus claw have been carried out in collaboration with Dr. C. A. G. Wiersma, and their results will be described in a subsequent paper.

II. Magnesium. In all three crustaceans studied [Mg^{++}] had exactly the same effect. The amplitude of contraction was inversely proportional to the amount of this ion present in the perfusate. The effects of changes in the magnesium concentration were the most readily reproducible and regular of the ions tried and recovery from moderate increases in its concentration were nearly as rapid as the original amplitude decrease. The site of the Mg^{++} depression was not the nerve, as increases in the amount of this ion result in increased nerve action currents (in whole crab leg nerve, Katz, '36, p. 215). The present results give no evidence for limiting the place of action further. In vertebrates excess magnesium causes a decrease in the excitability of denervated skeletal muscle (Maaske and Gibson, '39) as well as a "curare like" effect at the neuromuscular junction. Katz ('36) reports a curare effect of magnesium in crabs. However, since no definite effect on autofacilitation of excess Mg^{++} appeared in my own experiments even with concentrations of this ion sufficiently high to cause a marked decrease in contraction amplitude, further experimentation on the whole problem of facilitation will be necessary in order to analyze these relations more satisfactorily.

III. Calcium. The results obtained in all three forms by varying the amount of calcium present in the perfusion fluid were quite irregular, and the principal generalization which can be made is that any deviation as great as $\frac{1}{3}$ to $\frac{1}{2}$ Ca or 2 to 3 Ca resulted in irregular contractile behavior sometimes accompanied by spontaneous contractions. There

was also some evidence that changes in [Ca^{++}] affected the fast and slow fibers in qualitatively different ways, but more extensive data would be necessary for a detailed study of this phenomenon.

IV. Conclusion. In general the results of the present experiments are of interest for two reasons. First they afford a concrete basis for comparing perfusion experiments carried out with stimulation of the neuromuscular system of Crustacea through the whole nerve, including as it does fast and slow motor fibers and peripheral inhibitory fibers, and through isolated single motor nerve fibers. This comparison clearly indicates the possibilities and limitations of the former method of stimulation which has been the only one employed in previous experiments on perfused crustacean neuromuscular systems. Second, they have demonstrated a useful tool with which to attack the problems involved especially in the differences between the crustacean fast and slow neuromuscular systems since potassium certainly, and perhaps calcium produce qualitatively different changes in the two systems.

SUMMARY

1. A comparative study of the effects of ions on the perfused neuromuscular system of three crustaceans: Panulirus, Maia, and Cambarus, has been made. Experiments were conducted by recording isometrically the contractile response of the flexor dactyl muscle to stimulation of the whole leg nerve in all three forms and to stimulation of isolated single motor nerve fibers in Cambarus.

2. The magnesium ion was found to have similar effects in all the animals studied and in both the whole nerve and the single fiber preparations. The isometric tension developed in response to a brief tetanizing stimulation varied inversely with the amount of Mg^{++} present in the perfusion fluid, being greatest when none of the ion was present and approaching zero when more than four to five times the normal amount were perfused.

3. Potassium, on the other hand, affected the whole nerve preparations and the single nerve fiber preparations of the slow closer system differently from single nerve fiber preparations of the fast closer system. Increased K^+ led to decreased contractile responses in the former and to markedly increased contractile responses in the latter. Exactly comparable results were found when both the slow and the fast closer motor fibers were prepared and alternately stimulated in the same nerve muscle preparation. Evidence is cited suggesting that these potassium effects occurred at the myoneural junction in some of the steps involved in neuromuscular transmission.

4. Changes in the calcium content of the perfusion fluid usually gave rather irregular results, but some single fiber experiments suggested that with this ion, too, qualitatively different effects were produced on the slow and fast neuromuscular systems.

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TRANSPORT OF THE FLORIDA CURRENT OFF HABANA

By

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INTRODUCTION

This report is an analysis of four *Atlantis* sections across the Florida Current in the locality between Key West and Habana. In particular the volume transport of the current is calculated from the mass distribution observed on these four sections. The assumptions for the calculations are critically discussed, making use of records of sea level at Key West.

The first section, 4 March 1934 (stations 2003–2008), was made during Cruise 25 under the leadership of Dr. A. E. Parr (*Bulletin Hydrographique pour l'année 1934*, pp. 45, 111). The second section, 19–20 February (stations 2343–2347), and third section, 12–13 April 1935 (stations 2434–2438), were made during Cruise 41 by Dr. Parr and by Mr. Y. H. Olsen respectively (*Bulletin Hydrographique pour l'année 1935*, pp. 51, 100, 102). The fourth section, 24–25 March 1938 (stations 3006–3012), was made during Cruise 74 by Mr. Alfred H. Woodcock.

This region of the Straits of Florida had been investigated during February–May 1887 by Pillsbury (1887, 1890), who carried out extensive current measurements down to 130 fathoms from the *Blake* at anchor. A section of temperature by means of reversing thermometers and of salinity was made from the *Bache* in March 1914 (Bigelow, 1915).[2] Wüst (1924) attempted a dynamic calculation from the *Bache* material, but found the observations insufficient. *Dana* stations 1224–1229 were made in this region in February 1922,

[1] Contribution No. 303.

[2] In May 1878 the temperature at a number of points between surface and bottom for five stations on this section of the Straits had been determined from the *Blake* (Agassiz, 1888, Fig. 157). Within a few years of the same time another temperature section from the *Blake* was made farther west, approximately along the 84th meridian, but the date is not stated (Lindenkohl, 1895, Diagram No. 4).

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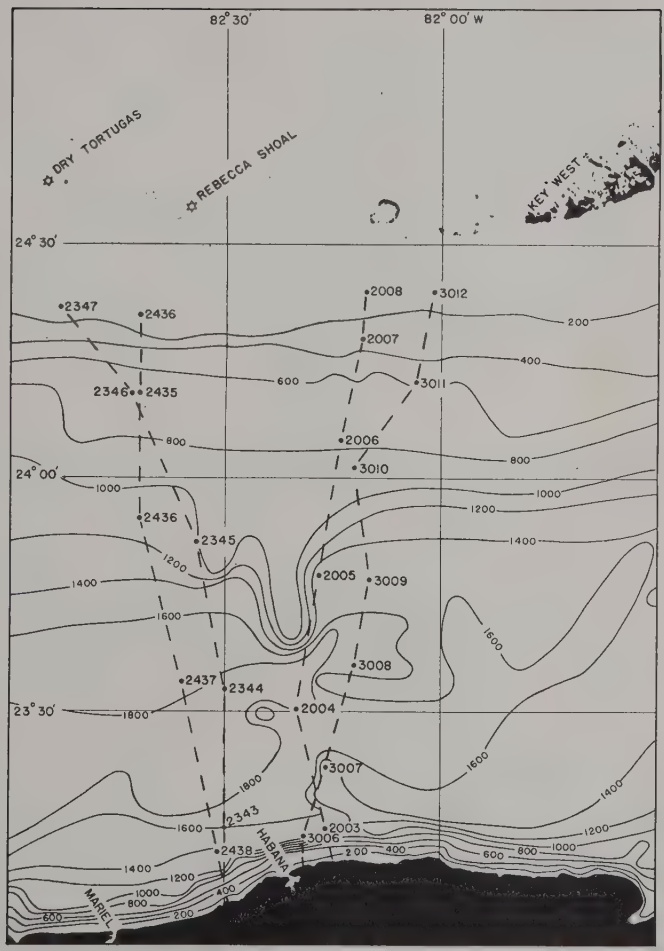

Figure 42. Station positions for the four *Atlantis* sections near Habana in the Straits of Florida. Isobaths are shown for each 200 meters.

three of them forming a section across the Straits (Schmidt, 1929).[3] In February 1932 a section consisting of *Mabel Taylor* stations 401–406 was made by Parr (1935). Parr shows temperature and salinity cross-sections for the *Dana* and *Mabel Taylor* sections and for the first *Atlantis* section, March 1934, and temperature-salinity curves for these as well as the *Bache* section. He discusses the origin of the waters found in these sections and finds them to be largely unadulterated Caribbean water but partly, especially in the northern part of the surface layers, of Gulf of Mexico origin.

The *Dana* and *Mabel Taylor* sections are not suitable for inclusion in this study. In neither case were unprotected thermometers used in determining the sampling depths. Furthermore the former consists of only three stations, while on the latter section the southernmost station lies 12 miles from the Cuban shore, so both are definitely less complete than the *Atlantis* sections.

METHOD

The positions of the stations are shown in Figure 42. The isobaths on this chart were constructed from the soundings entered on U. S. Coast and Geodetic Survey Chart No. 1113 (United States—Gulf Coast, Habana to Tampa Bay, March 1933, reissued July 1938). The soundings are so sparse that the contours are not at all reliable. No adequate sounding survey has been made of any part of the Straits of Florida except the shallow coastal areas. This imposes a severe restriction on studies of the flow through the Straits.

The anomaly of specific volume (0° C and salinity 35 per mille as standard) was computed from the observed temperature, salinity and depth for each sample by Sverdrup's (1933) tables. The complete data and computed values for observed depths are given for the fourth section in Table I. Since temperature, salinity and oxygen values for the first three sections have already been published these sections are not repeated here in tabular form.

Anomaly of specific volume was plotted against depth and a smooth curve drawn for each station. The depths of chosen standard values of anomaly of specific volume were determined from these curves and then entered on the cross-sections, and finally the isopleths of anomaly of specific volume were drawn, giving Figures 43–46. Few of the stations reach near the bottom, so considerable uncertainty was involved in extrapolating the isopleths to the walls of the Straits.

[3] The temperature and salinity cross-section is shown by Nielsen (1925, Fig. 2). See also Jacobsen (1929).

Smooth salinity-depth curves were constructed for each station, from which the depths of 36.4 and 36.6 per mille were determined and entered on the cross-sections. On this basis the areas of the salinity maximum are indicated in Figures 43–46. These may be correct in their broadest features, but the sampling in the upper 300 meters was too coarse to define clearly the thin layer of high salinity, which occurs near the depth of maximum stability.

In order to integrate the hydrostatic equation the station curves of anomaly of specific volume were extended where necessary to 1200 meters, or to the bottom at shallower stations, by use of the isopleths on the cross-sections. Likewise smooth curves of anomaly of specific volume versus depth have been drawn for both walls of each section. By integrating along these curves, using depth in meters to represent pressure in decibars, the anomaly of geopotential above 1200 db was found for the intersections of each station vertical and of the walls with the standard isopleths of anomaly of specific volume and with the sea surface. The resulting values for the sea surface at the northernmost station and at the Cuban shore are given in Table II. The acceleration potential (Montgomery, 1937; Montgomery and Spilhaus, 1941),

$$\Upsilon = \Phi_a + \delta p$$

(where Φ_a is anomaly of geopotential, δ is anomaly of specific volume and p is pressure), was found for all the intersections.

The volume transport through an area bounded by two successive station verticals (or the wall and adjacent station) was found from the expression

$$\Delta V = \frac{\Delta \Upsilon \Delta z}{f}.$$

Here Δz is the average distance between the two isopleths, f is the Coriolis parameter computed for the mid-latitude of each pair of stations, and $\Delta \Upsilon$ is the average, for the two isopleths, of the difference in acceleration potential between the two verticals. The sums for each complete layer and for each section are given in Table III. The transport through the small area lying north of the northernmost station was neglected in each case.

As a check, the total transport for each section was also computed directly from the expression

$$V = \frac{1}{f}\left[\int_{\text{right}} \Phi_a \, dz \; - \int_{\text{left}} \Phi_a \, dz\right]$$

TABLE I—*Atlantis* Habana Section, 24–25 March 1938

Station	*Depth* (*meters*)	*t* ° *C*	*S* °/₀₀	σ_t *g* l^{-1}	δ *cl* ton^{-1}
3006, 24 III 38	1	26.03	35.79	23.64	427
1715–1820	24	25.97	35.90	23.74	418
23° 14′ N, 82° 19′ W	47	25.90	35.91	23.77	416
Depth 1463–1372 meters	94	25.60	36.00	23.94	402
Wind force 3	141	23.85	36.58	24.90	312
	188	20.92	36.74	25.86	222
	282	17.77	36.45	26.46	168
	376	14.29	35.84	26.79	138
	470	11.21	35.35	27.03	115
	564	9.09	35.07	27.175	102
	752	6.59	34.87	27.39	81
	938*	5.38	34.90	27.575	64
	1128	4.59	34.94	27.70	53
3007, 24 III 38	1	26.01	35.91	23.74	417
1935–2140	44	25.96	35.91	23.75	418
23° 23′ N, 82° 16′ W	82	25.71	36.00	23.905	405
Depth 1710 meters†	119	23.61	35.97	24.51	348
Wind force 3	157	19.91	35.93	25.52	253
	233	18.29	36.47	26.34	178
	308	14.66	35.97	26.81	134
	383*	12.77	35.62	26.94	123
	446	11.12	35.35	27.05	113
	572	8.11	34.96	27.24	95
	699	6.51	34.87	27.40	79.5
	825*	5.53	34.87	27.53	67
	1099*	4.34	34.97	27.75	47
3008, 24–25 III 38	1	25.90	35.93	23.79	412
2255–0105	38	25.92	35.93	23.78	415
23° 36′ N, 82° 12′ W	66	24.25	36.00	24.35	361.5
Depth 1701 meters	89	21.25	35.95	25.16	285
Wind force 2	114	19.62	35.93	25.59	245
	165	18.60	36.38	26.20	189
	216	16.20	36.13	26.59	153
	267*	14.51	35.86	26.76	138
	302	13.15	35.66	26.89	126
	371	10.72	35.28	27.06	110
	440	9.18	35.07	27.16	101
	509*	8.05	34.96	27.25	92.5
	640*	6.31	34.88	27.44	75

TABLE I—*Cont.*

Station	*Depth* (*meters*)	*t* ° *C*	*S* °/₀₀	σ_t *g* l^{-1}	δ *cl* ton^{-1}
3009, 25 III 38	1	24.99	36.06	24.16	377
0245–0358	49	21.42	36.36	25.44	257
23° 47′ N, 82° 10′ W	97	19.72	36.35	25.88	217
Depth 1508 meters	144	17.35	36.29	26.44	165
Wind force 2	191	15.34	36.04	26.71	140
	286	11.64	35.44	27.015	113
	381	8.59	35.01	27.215	94
	476*	7.28	34.90	27.32	84
	570	6.36	34.88	27.43	75
	779	5.05	34.92	27.625	57
	987	4.59	34.94	27.70	51
	1196*	4.26	34.96	27.74	49
	1389*	4.14	34.99	27.785	46
3010, 25 III 38	1	24.77	36.04	24.21	372
0530–0620	25	23.58	36.33	24.79	318
24° 01.5′ N, 82° 12′ W	50	20.95	36.33	25.54	247.5
Depth 878 meters	100	18.73	36.36	26.15	191
Wind force 1	150	15.88	36.08	26.615	148
	199	13.53	35.71	26.85	127
	298	10.19	35.21	27.11	103
	397*	8.09	34.96	27.245	91
	495	6.84	34.87	27.36	81
	594	5.98	35.01‡	27.59	59.5
	793*	.06	34.90	27.61	59
3011, 25 III 38	1	24.55	36.10	24.33	361
0830–0915	25	23.51	36.31	24.79	318
24° 12.5′ N, 82° 03.5′ W	50	20.77	36.36	25.62	240
Depth 539 meters	100	17.15	36.27	26.47	161
Wind force 2	149	14.65	35.91	26.77	133
	198	12.70	35.61	26.94	118
	297	10.47	35.28	27.10	104
	395*	9.18	35.08	27.17	99
	493	7.81	34.94	27.28	89
3012, 25 III 38	1	24.33	36.27	24.52	343
1030–1055	25	21.32	36.38	25.47	253
24° 24′ N, 82° 01′ W	50	19.80	36.31	25.83	220
Depth 161 meters	75	18.50	36.36	26.21	185
Wind force 2	100	15.62	36.08	26.67	141.5
	150	11.57	35.41	27.01	109.5

* Depth determined with unprotected reversing thermometer.

† At this position Chart No. 1113 shows sounding of 710 fathoms or 1300 meters.

‡ Looks very doubtful on $\sigma_t - S$ diagram, so this observation has been omitted from consideration.

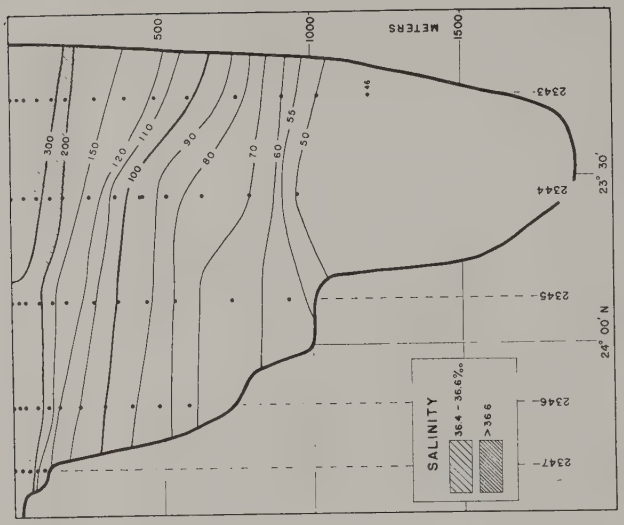

Figure 44. *Atlantis* Habana section on 19–20 February 1935 showing distribution of anomaly of specific volume in centiliters per ton. Vertical exaggeration about 100.

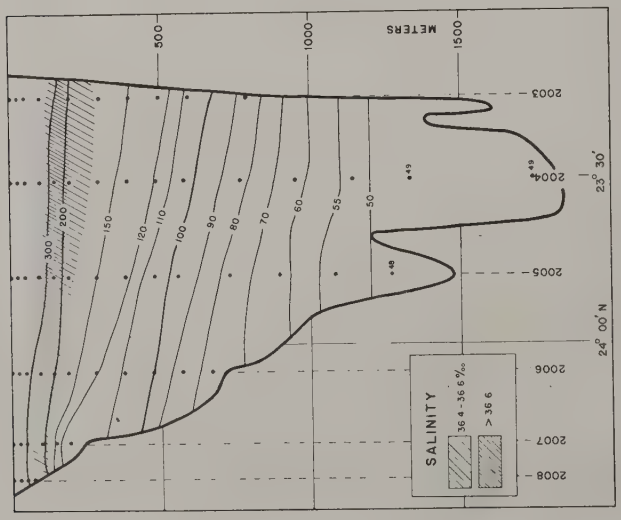

Figure 43. *Atlantis* Habana section on 4 March 1934 showing distribution of anomaly of specific volume in centiliters per ton. Vertical exaggeration about 100.

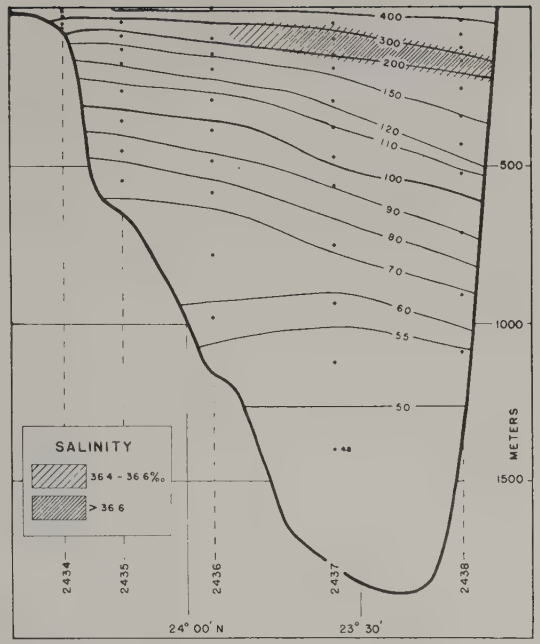

Figure 45. *Atlantis* Habana section on 12–13 April 1935 showing distribution of anomaly of specific volume in centiliters per ton. Vertical exaggeration about 100.

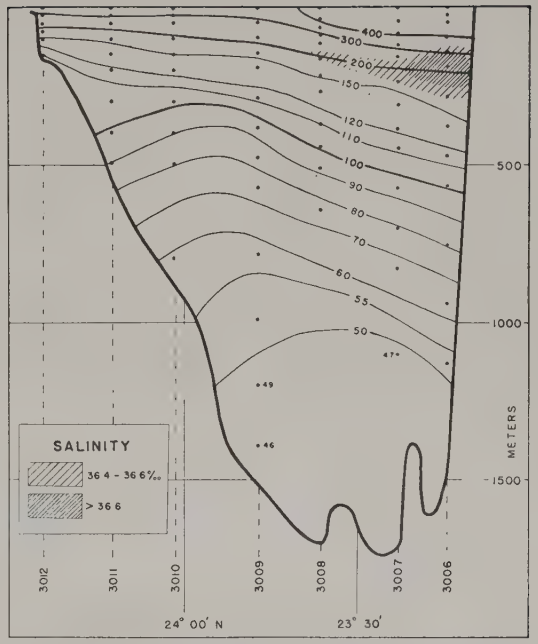

Figure 46. *Atlantis* Habana section on 24–25 March 1938 showing distribution of anomaly of specific volume in centiliters per ton. Vertical exaggeration about 100.

TABLE II—Anomaly of Geopotential, in Kilergs per Gram, Relative to 1200 db of the Sea Surface at the Northernmost Station of Each Section and at the Cuban Shore

Date	*4 III 34*	*19–20 II 35*	*12–13 IV 35*	*24–25 III 38*	*Means*
Station No.	*2008*	*2347*	*2434*	*3012*	
Northern station	122.9	104.9	112.0	108.6	112.1
Cuban shore	170.4	172.4	172.5	170.6	171.5
Difference	47.5	67.5	60.5	62.0	59.4

TABLE III—Eastward Transports, in Million Cubic Meters per Second, Between Successive Isopleths of Anomaly of Specific Volume

δ *cl ton*$^{-1}$	*4 III 34*	*19–20 II 35*	*12–13 IV 35*	*24–25 III 38*	*Means*
>400	0.00	0.00	2.34	4.97	1.83
300–400	7.67	9.35	6.37	3.81	6.80
200–300	3.78	6.24	4.80	4.61	4.86
150–200	5.76	4.83	4.38	3.94	4.73
120–150	3.38	3.74	4.00	3.59	3.68
110–120	1.40	1.39	1.28	1.31	1.34
100–110	1.54	1.63	2.38	1.11	1.66
90–100	1.09	1.42	1.67	0.98	1.29
80–90	0.70	0.86	1.05	0.82	0.86
70–80	0.41	0.75	0.63	0.60	0.60
60–70	0.21	0.12	0.10	0.44	0.22
55–60	0.07	−0.07	−0.01	−0.04	−0.01
50–55	0.02	0.02	0.00	−0.13	−0.02
Sums	26.0	30.3	29.0	26.0	27.8

(Jakhelln, 1936, p. 4), where z is elevation above the depth of 1200 meters and the integrations are performed for the walls. The agreement was good in each case.

The freedom allowed in extrapolating the mass distribution where there are no samples involves great uncertainty. For instance, the isopleths for the first section as shown in Figure 43 appear to give a reasonable interpretation on the basis of the observations, and give a total transport of $26.0 \cdot 10^6$ m^3sec^{-1}. However, another interpretation, appearing nearly as reasonable, gave $29.2 \cdot 10^6$ m^3sec^{-1}. The uncertainty in regard to the anomaly of dynamic height above 1200 db is relatively less. The two calculations for the first section give, in kilergs per gram:

	First calculation	*Second calculation*
Northern station	121.8	122.9
Cuban shore	171.8	170.4
Difference	50.0	47.5

Since the two calculations differ by much less than do the different sections as given in Table II, the values in that table are not in serious error due to incomplete knowledge of the mass distribution.

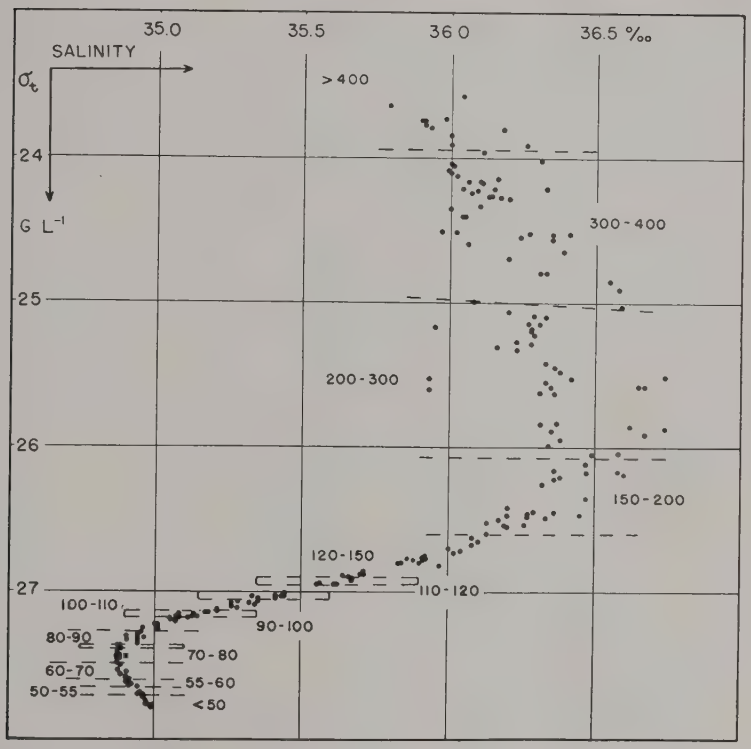

Figure 47. σ_t-Salinity correlations for all observations on the four *Atlantis* Habana sections, indicating also the anomaly of specific volume in centiliters per ton.

The base level of 1200 db was chosen rather than a deeper one because almost no observations below it were obtained.

Integration of curves of anomaly of specific volume versus pressure for the walls in order to obtain the anomaly of geopotential at points along the walls of course involves the questionable assumption that the horizontal pressure gradient vanishes at the walls.

When first suggested it was supposed that the acceleration potential would be computed for σ_t-surfaces, since these are usually best suited for isentropic analysis (Montgomery, 1937). The anomaly of specific volume is not entirely constant over a σ_t-surface (cf. Montgomery, 1938a, pp. 20–22), so $\Phi_a + \delta p$ is not strictly an acceleration

potential for such a surface and its use gives only approximate results. Accordingly, since surfaces of constant anomaly of specific volume have an exact acceleration potential, these have been used in the present study. This however introduces some inconvenience because specific volume anomaly is considerably less conservative than σ_t. This is illustrated by Figure 47, showing the overlapping with respect to σ_t of the layers of anomaly of specific volume.

In passing through the Straits the Florida Current turns cyclonically through nearly a right angle. Although there is no precise information on the direction of flow in all parts of the Straits, it is probable that the curvature starts before the Current reaches the Habana section. Since the cyclostrophic term in the equation of motion was neglected above in computing transport, the transports tabulated above are slightly too large. The radius of curvature of the axis of the Florida Current where it crosses the Habana section is about 500 km according to the U. S. Coast and Geodetic Survey Chart No. 1113. In the axis of the Current, where the speed is about 120 cm sec^{-1}, this would make the ratio of the cyclostrophic term to the Coriolis term 0.04. Taking the cyclostrophic term into account reduces the transport for the March 1934 section by 0.35 million cubic meters per second, or 1.3 per cent. This is so small, and the radius of curvature is so uncertain, that the correction term may suitably be neglected.

Each observation on all four sections is entered in Figure 47, which therefore serves also to show both the range of salinity and the average value for each layer of anomaly of specific volume. In the original drawing the points were differentiated according to the layers. This is indicated in the figure by broken lines. Where there is overlapping, two lines indicate the range of overlapping.

DISCUSSION

Pressure gradient at the bottom

The transport calculations were carried out on the assumption that there is no cross-stream horizontal pressure gradient at the bottom. It was at the Miami section of the Straits of Florida that Wüst (1924, p. 37) obtained his famous agreement between Pillsbury's current measurements and the density distribution deduced from *Blake* and *Bache* observations. His calculation of velocity distribution from density distribution was based on the absence of horizontal pressure gradient at the depth of the temperature minimum[4] in the

[4] Subsequent observations have not confirmed the existence of this temperature minimum. The temperature higher than 9° near the bottom as shown by Wüst therefore seems in error by several degrees.

central portion of the section, and at the bottom on the sides where the temperature minimum is lacking. Since the temperature minimum is shown less than 200 meters from the bottom, this gives evidence that the gradient is quite small at the bottom itself. In addition to this evidence and to the general fact that currents tend to be weak in deep water there are several considerations which indicate that the bottom gradient is small at the Habana section.

(1) *Bottom friction.* Any cross-stream pressure gradients which may arise at the bottom are automatically reduced by friction. This can be quite effective because the sources of currents and pressure gradients are to be found almost exclusively in the surface layers. For instance, in the deep central part of any section of the Straits of Florida a pressure gradient may arise due to some temporary cause. Bottom friction prevents complete development of a current to balance this pressure gradient, with the result that water flows from higher to lower pressure. Due to the confinement of the Straits a relatively small cross-stream transport of this sort is effective in reducing the gradient. It is unlikely that the cause of the gradient can be of both long duration and considerable magnitude, so bottom friction keeps the gradient small except for brief sporadic periods.

The "walls" of the Straits may be considered from the point of view of any layer bounded above and below by surfaces of constant potential density. This is largely an independent unit as far as frictional forces are concerned. In the central part of the layer the water is flowing through the section as part of the Florida Current, and the cross-stream pressure gradient is closely adjusted to this flow. Due to lateral friction (if not to other causes) the velocity gradually reduces to zero on approaching the wall at either side. Also in this manner adjustment of the pressure gradient takes place if possible, so that it tends to decrease toward zero at the walls.

(2) *Threshold.* The dense water of the lower layers found in the Habana section of the Straits cannot pass through the shallower sections further downstream. The threshold depth of the Straits is not well determined, but may be estimated very roughly as 800 meters. The threshold lies near Miami and the maximum σ_t observed in four sections from this vicinity are given in Table IV.

TABLE IV—Maximum Values of σ_t Observed on Four Miami Sections

Section	*Station*	*Depth (meters)*	*Temp* ° *C*	*Salinity* °/₀₀	σ_t $g\ l^{-1}$
Bache 19–20 III 14 (Bigelow, 1915, p. 58)	10203	800	6.16	34.85	27.43
Atlantis 17–23 IV 37 (Parr, 1937, Figure 3)	2855	600	6.00	34.90	27.50
Atlantis 27–28 III 38 (unpublished)	3016	579	7.45	34.91	27.305
Atlantis 22–23 V 39 (unpublished)	3506	729	6.06	34.88	27.475

From these values it may be concluded that very little water denser than $\sigma_t = 27.50$ g l^{-1} passes through the Straits. According to Figure 47 this coincides with an anomaly of specific volume of 70 cl ton^{-1} at the Habana section, so that the transport of the layers below this must be very small. The computed transports as given in Table III agree fairly well with this conclusion, showing that the assumption of no cross-stream pressure gradient at the bottom has led to only a slight inconsistency in this respect.

(3) *Current observations.* In Table V are given the surface currents measured from the *Blake* on the Habana section during parts

TABLE V—Pillsbury's Measurements of Current at 3½ Fathoms Below the Sea Surface on the Habana Section, February–May 1887

Station	*Miles south of Rebecca Shoal Light (24° 35′ N, 82° 35′ W)*	*Current strength (knots)*	*Current direction**	*East component cm sec⁻¹*	$\frac{d\Phi}{dx}$ *cm sec⁻²*
1	18	0.32†	——	16	0.0010
2	34½	0.96	SE x E½E	43	0.0026
3	50½	2.20	E ¼ S	113	0.0066
3½	59	1.77	E ¾ S	90	0.0052
4	67	2.35	E x N	119	0.0069
4½	75½	1.13	NE x E½E	51	0.0029
5	84	0.87	NE ½ N	29	0.0017

* From the small table on page 176 of Pillsbury's paper.
† East component.

of the months February–May 1887, taken from Pillsbury's (1887, Illustration No. 38, Fig. 1) graphical summary. The east component has been computed and in the last column is given the gradient of geopotential at the sea surface along the section,

$$\frac{d\Phi}{dx} = fv.$$

Here v is the east component of the current, and for each station the appropriate latitude has been used in computing the Coriolis parameter. The values of gradient in Table V have been integrated to give the geopotential of the sea surface along the section, represented by the continuous curve in Figure 48.

The same figure shows the geopotential of the sea surface as computed for each station of the four *Atlantis* sections. The form of the curve based on current measurement agrees well with an imaginary average of the four curves based on density distribution and on the assumption of no cross-stream horizontal pressure gradient at the bottom. In magnitude, the curve from current measurements is 52 kilergs g^{-1} higher at the Cuban shore than at the northern end,

whereas the differences between the Cuban shore and the northernmost stations of the *Atlantis* sections range between 47.5 and 67.5 kilergs g^{-1} (Table II).

This comparison cannot lead to definite conclusions because the two types of measurements were made at different times. The height difference from current measurements falls within the range of values from the four *Atlantis* sections, but is 7 kilergs g^{-1} less than the average of the latter. This indicates that the assumption of no cross-stream horizontal pressure gradient at the bottom is not consistently in large error, but that perhaps there is a tendency for

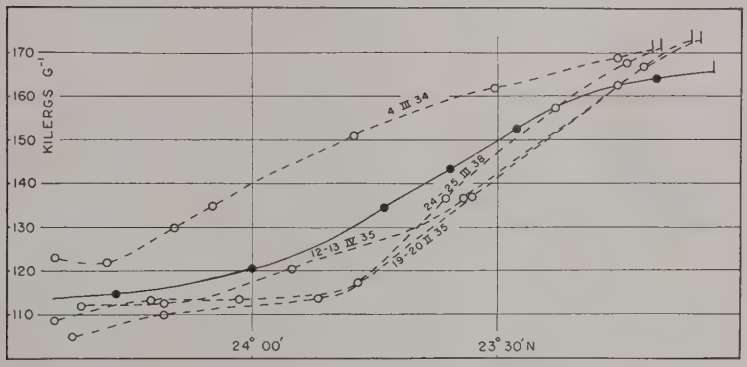

Figure 48. Profiles of sea surface at Habana section of the Straits of Florida. Solid line computed from *Blake* current measurements during February–May 1887. Broken lines computed from the mass distributions on the *Atlantis* sections, the ordinate being anomaly of geopotential above 1200 db. Vertical exaggeration about 10^5.

pressure at the bottom to decrease horizontally toward the right of the stream.

Tidal effects

Each of the four sections required about 16 hours to complete. The question arises as to what effect this lack of simultaneity may have on the observed mass distribution.

The tides and tidal currents in the Straits of Florida are of the mixed diurnal and semidiurnal type. The mean semidiurnal range of tide at Habana is 27 cm and the time of high water, 8^h 36^m after the moon's transit, is practically simultaneous with high water on the south side of the Florida Keys (Sombrero Key Light, American Shoal Light, Sand Key Light), where the mean range is 40 to 49 cm

(Coast and Geodetic Survey, 1940). It is reasonable to assume that the tide is similar all across the intervening strait. Since the range of tide is not identical on the two sides, however, there is necessarily a tidal variation in the cross-stream horizontal pressure gradient at the surface. The speed at the axis of the Florida Current also undergoes a tidal variation of amplitude about 14 cm sec^{-1}. To quote Pillsbury (1890, p. 608), "the maximum [flow] in the Straits of Florida is . . . 2 hours and 15 minutes after mean low water at the southern Atlantic ports of the United States." He further states that "off Cape Florida [Miami], there is but one prominent maximum each day, usually arriving 9 hours before the upper transit of the moon."

The *Atlantis* successively occupied five 24-hour anchor stations on a section crossing the Straits from Miami. The density distribution at the three western stations, 2854–2856, exhibit "a fairly distinct indication of a 12 lunar hours period in the upper 200 meters" (Parr, 1937, p. 20). The eastern stations, 2857 and 2858, "show no distinct periodicity with reference to lunar time." At the westernmost station, 2854 with depth of 375 meters, the geopotential of the sea surface above 300 db varied by 12 kilergs g^{-1}. At stations 2855–2858 the sea surface relative to 600 db varied by 30, 15, 6, 6 kilergs g^{-1} respectively (Parr, 1937, Figures 20, 21). Thus the variation is greatest where the slope of the isopycnals is greatest, and decreases toward the shore on each side.

Presumably similar conditions prevail at the Habana section. At the walls there may be little tidal or other short-period variation of density, so the calculated height of the sea surface at left and right shores and calculated total transport are not much affected. For these quantities, therefore, it is perhaps not significant that the density distribution was not measured simultaneously over the whole section. This conclusion is not substantiated by Parr's (1937, Table IV) values for every third lunar hour of the transport through the Miami section, which do vary. But this may easily be a fictitious variation, because (1) his sections for each third lunar hour are compositely formed from the anchor stations, (2) just as in the case of the Habana sections the observations do not completely determine the density distribution along the bottom, (3) he has not assumed the absence of horizontal pressure gradients at the bottom, which anyway is more doubtful at the constricted Miami section, and (4) his values do not include the considerable transport outside the two end stations.

If the tidal variations of density in the deep water and along the

walls are actually small, then the variations in horizontal pressure gradient at the surface must extend to the bottom. It is therefore probable that appreciable horizontal pressure gradients occur periodically at the bottom, but their average value may be expected to be small for reasons already stated. If so, they do not affect the calculation of total transport.

On the other hand there is a tidal lateral shift of the density distribution, producing large density variations at any point in the region of strong current. Hence the computed height of the sea surface at a station distant from the shore depends to large extent on the hour at which the station is occupied, and the computed transports of individual isosteric layers are presumably affected to a considerable degree.

Normal total transport through the Habana section of the Straits of Florida in March

By extrapolating his vertical velocity profiles downward from 130 fathoms, Pillsbury (1887, p. 179) obtained $103 \cdot 10^9$ tons per hour as the transport through the Habana section, which is equivalent[5] to about $28 \cdot 10^6$ m^3 sec^{-1}. A recalculation by Wüst (1924, p. 42) of the same measurements gave $24.15 \cdot 10^6$ m^3 sec^{-1}.

For comparison some estimated transports through other sections may be quoted. Wüst found for the Miami section $24.96 \cdot 10^6$ m^3 sec^{-1} based on the *Blake* current measurements and $25.55 \cdot 10^6$ m^3 sec^{-1} based on the density distribution deduced from *Blake* and *Bache* observations. For the same section Parr's (1937, p. 47) calculation from *Atlantis* anchor stations gives the transport as "somewhat more than" $30 \cdot 10^6$ m^3 sec^{-1}. From *Atlantis* stations made in 1933 and 1934 Parr computed 31.92 and 33.92 million cubic meters per second as the transport through the Yucatan Sea.

The values in Table III for the four *Atlantis* sections range from 26 to slightly over 30 million cubic meters per second. The fact that the two sections in March show lower values than the sections in February and April is probably not significant in regard to the annual variation of transport; in other words it should not be interpreted as indicating a minimum of transport in March. The four sections, all from nearly the same time of year, are probably sufficient to yield a significant estimate of the normal transport at this time. For no reason is it likely that these values differ consistently from normal by large amounts. In view of the scattering of the four values and of the possible error in the mass distribution as deduced

[5] Assuming the ton to be 2240 pounds.

TABLE VI—Departures from Normal in Centimeters of Daily Sea Level at Key West Reduced to Sea Level Pressure of 30.02 Inches (Normal Sea Level Is the Average for 1913–1939, Being Staff Reading of 4.95 Feet; Zero on Staff Is 13.06 Feet Below Bench Mark 29)

	III 34	*II 35*	*IV 35*	*III 38*
1	− 2.8	+ 8.1	− 1.6	− 3.6
2	− 2.3	+ 7.8	− 5.8	− 0.2
3	− 4.3	+ 6.5	− 4.0	− 3.6
4	− 7.5	+ 5.2	− 4.5	− 6.7
5	−12.1	+ 6.2	− 1.4	− 6.7
6	−10.7	+ 3.5	− 2.5	− 5.6
7	− 7.0	+ 2.7	− 1.9	− 7.0
8	− 7.5	+ 4.8	− 5.9	− 3.3
9	− 8.4	+ 4.1	− 3.0	− 2.6
10	− 9.2	− 2.5	− 3.0	− 5.9
11	− 9.7	− 1.3	− 1.8	− 6.7
12	− 8.1	− 3.7	+ 1.1	− 5.4
13	− 2.0	− 1.7	+ 3.1	− 5.2
14	− 5.1	− 5.6	+ 1.3	− 2.5
15	− 5.0	− 8.4	+ 3.8	− 5.0
16	− 1.8	− 9.6	+ 2.2	− 6.3
17	− 2.7	−13.7	+ 4.4	− 8.8
18	− 6.0	−17.8	+ 2.9	− 9.8
19	−12.3	−14.8	+ 4.2	− 6.9
20	−13.3	−11.9	− 0.7	− 5.4
21	−10.3	−10.5	− 3.7	− 4.7
22	− 7.2	− 4.5	− 2.3	− 1.8
23	− 7.1	− 4.6	− 1.7	− 1.8
24	− 5.3	− 8.2	+ 0.9	− 5.1
25	− 0.1	− 8.4	+ 0.4	− 5.8
26	+ 1.4	− 5.6	+ 1.5	− 3.6
27	+ 1.2	−10.7	+ 2.1	− 5.1
28	− 7.3	−11.8	+ 3.0	− 3.5
29	− 9.5		+ 0.4	+ 0.4
30	− 9.7		− 2.8	− 1.4
31	− 7.4			− 4.2
Means	− 6.4	− 3.8	− 0.5	− 4.6

from the observations it seems best to state the conclusion as follows: It is highly probable that the normal total transport through the Habana section of the Straits of Florida in March is a value lying between 26 and 30 million cubic meters per second.

The individual values obtained deviate from normal due to (1) actual departures of the transport from normal, (2) error in determining the mass distribution, (3) effect of tide on the mass distribution, and (4) presence throughout the tidal cycle of cross-stream horizontal pressure gradients at the bottom and of a deviation of the current from complete geostrophic flow.

Comparison with tidal station at Key West

Dietrich (1937, Abb. 15), Montgomery (1938b, pp. 166–169) and La Fond (1939, pp. 18–19) have found for specific localities a fair agreement between monthly or weekly sea level at tidal stations and fluctuations in sea level as computed from the vertical density distribution at nearby oceanographic stations. Good opportunity for such a comparison is offered by the northern station of each of the Habana sections, which lie near the primary tidal station at Key West.

The Director of the Coast and Geodetic Survey has kindly supplied the daily sums of the hourly heights of tide at this station for the months of the four sections. These have been converted to departures from the normal staff reading of 4.95 feet (Montgomery, 1941, Table I). To these departures were added the departures from normal of atmospheric pressure expressed in terms of a water barometer (departure in centimeters of water is 34.532 times the departure in inches of mercury), Table VI giving the resulting values. The pressure used was the average for hours 0800 and 2000, 75th meridian time, which were supplied by the Chief of the Weather Bureau. In regard to whether the tide is largely eliminated by this procedure, Marmer (1931, p. 51) says "it is sufficient to derive daily sea-level as the average of the 24 hourly heights of the tide of the civil day."

Table VII gives a comparison of computed sea level for the northern

TABLE VII—Comparative Values of Sea Level in Centimeters

Date	*4 III 34*	*20 II 35*	*12 IV 35*	*25 III 38*	*Range*
Northern station	+11.0	− 7.4	−0.1	−3.6	18.4
Key West { *day*	− 7.5	−11.9	+1.1	−5.8	13.0
Key West { *7 days*	− 6.7	−11.1	+0.2	−3.8	11.3
Key West { *month*	− 6.7	− 3.9	−0.9	−4.7	5.8

station, from Table II, with sea level at Key West for the appropriate day and for the seven days centered on the appropriate day, from Table VI. Mean sea level for the calendar month also is reproduced (Montgomery, 1941, Table I).

Monthly sea level at Key West shows no agreement with computed sea level at the northern station, while the daily and weekly values, which differ only slightly from each other, perhaps do show slight agreement with the northern station. The greatest disagreement is for the first section; compared with the averages of the other three it differs from the daily value at Key West by 14.4 cm. No extreme weather conditions prevailed when any of the sections were made.

Some of the discrepancy may be due to an actual difference in sea level between Key West and the northern station of the section. Evidence that sea level at Key West is perhaps not representative of conditions in the offshore water is to be found in the marked variations in the fall of sea level from Key West to Miami, individual monthly values ranging from — 3.1 cm to 11.9 cm (Montgomery, 1941).

On the other hand if there is little difference in sea level between Key West and the northern station, and if the density distributions for the four sections were correctly extrapolated to the northern wall and their tidal variation and horizontal pressure gradients at the wall are negligible, there must be a non-tidal variation in elevation of the 1200-db surface. Although such pressure variations in deep water have not heretofore been noted, it is conceivable that they should exist, especially in the partially enclosed Central American seas, where the circulation and density distribution is controlled by the variable trade wind system.

Fluctuations in transport of the Florida Current

The computed transport for each of the four sections was given in Table III. Due to the uncertainties already discussed the significance of the fluctuations is questionable, although their magnitude is quite as one might expect.

If the computed fluctuations are essentially real, there is value in comparing them with the computed sea level difference across the Straits, as in Table VIII. The agreement between sea level differ-

TABLE VIII—Transport of the Florida Current in Million Cubic Meters per Second in Relation to the Computed Sea Level Difference Across the Straits (from Tables 2 and 3)

Date	*4 III 34*	*19–20 II 35*	*12–13 IV 35*	*24–25 III 38*
Sea level difference, kilergs g^{-1}	47.5	67.5	60.5	62.0
Total transport	26.0	30.3	29.0	26.0
Transport above δ = 200 *cl ton*$^{-1}$	11.4	15.6	13.5	13.4
Transport above δ = 300 *cl ton*$^{-1}$	7.7	9.4	8.7	8.8

ence and total transport is poor. The sea level difference is however seen to be closely correlated with the transport of water having

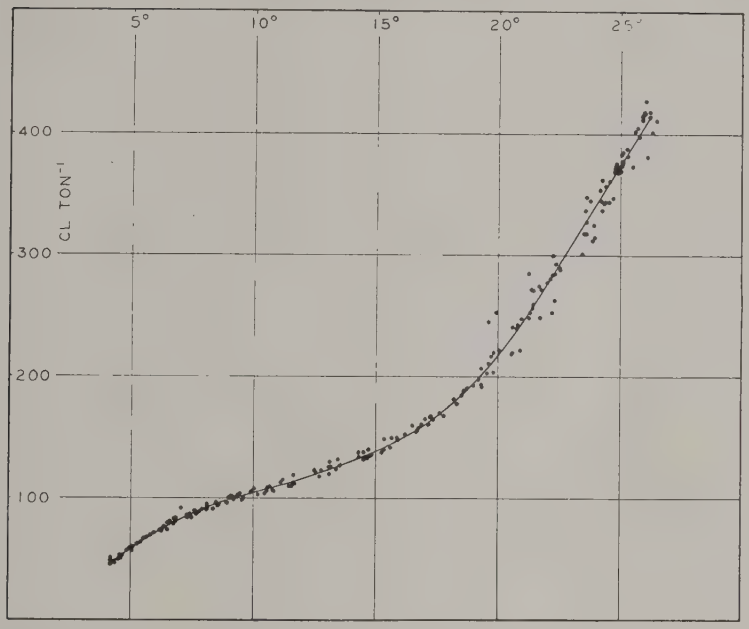

Figure 49. Correlation of temperature with anomaly of specific volume for all observations on the four *Atlantis* Habana sections.

anomaly of specific volume greater than 300 cl ton^{-1} (warmer than about 23° C) or greater than 200 cl ton^{-1} (warmer than about 19.2° C, see Figure 49). This suggests that fluctuations in the transport of warm water through the Straits might be measured with a pair of tidal stations placed on opposite sides and in good exposures. Perhaps the pair of stations now operating further downstream, at Miami and Cat Cay, will prove to serve this purpose at that section.

The deep counter current on the left of the Florida Current

On all the four sections except the first the deeper isopleths of anomaly of specific volume dip downward toward the northern wall (Figures 43–46), indicating a counter current. The calculations showed negative velocities extending up to anomaly of specific volume 70 cl ton^{-1} or 600 meters on the second section, up to 80 cl ton^{-1} or 500 meters on the third section, and up to 200 cl ton^{-1} or 80 meters on the fourth section.

In regard to this section Pillsbury (1890, p. 551) states: "The current does not fill the banks . . . , but has on its northern edge a neutral zone of varying width, in which, at times, there is an eddy current setting to the westward. At Station 1, which is within this zone and about 3 miles from the 100-fathom curve, tidal currents were always found except on one occasion, . . ." According to the data (Pillsbury, 1887, Illustrations Nos. 35 and 36) this station was occupied for about 24 hours on each of three occasions. On the first occasion the current was predominantly about a half knot west at 65 and 130 fathoms and irregular above that. On the other two occasions the current at the deeper levels was irregular, and at higher levels it was predominantly west in one case and east in the other. Pillsbury's measurements do not extend down to the depths where the *Atlantis* sections indicate a predominant counter current.

The counter current appears therefore to be a normal feature of the Habana section of the Straits in late winter. It is most persistent at depths immediately below the threshold of the Straits; it often extends much higher, but there is apparently no evidence that it ever reaches completely to the sea surface. Thus there is reason to believe that the counter current does not extend far eastward, and that it is a characteristic of the deep embayment upstream from the threshold, where also the Florida Current is closest to the right bank.

SUMMARY

A total of four hydrographic sections crossing the Straits of Florida near Habana were executed from the *Atlantis* during the winter months of 1934, 1935 and 1938. From the observed mass distribution the water transport in various layers (defined by surfaces of constant anomaly of specific volume) has been computed by use of the acceleration potential (Table III). The computed total transport varies for the four sections from 26.0 to 30.3 million cubic meters per second, and the conclusion was drawn that probably the normal transport in March is a value lying between these extremes. The assumptions and various sources of error involved in the calculation have been discussed.

The four values of sea level computed for the northern end of the sections show no appreciable correlation with sea level observed at the nearby tidal station at Key West.

The computed difference of sea level across the Straits shows little correlation with the computed total transport, but good correlation with the computed transport of the lighter surface water.

A counter current in the deep water on the left of the Florida Current appears to be a characteristic of this part of the Straits.

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Contribution No. 306

OBSERVATIONS ON TRANSPARENCY IN THE SOUTHWESTERN SECTION OF THE NORTH ATLANTIC OCEAN

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The present measurements were undertaken to extend our knowledge of the transparency of ocean waters to areas to the south of the Bermuda region and to the east of the Caribbean region beyond the limits of earlier investigations (Oster and Clarke, 1935; Clarke, 1938 and 1939). The measurements were made from the research vessel "Atlantis"* between January 19, 1941 and March 7, 1941 on Cruise No. 111 which extended from Bermuda to the northeast coast of South America and back to New York. The positions of all stations where observations were made are indicated in Figure 50.

It was desired not only to determine what variations existed in the average transparency of the different areas of the sea traversed, but also to ascertain whether any changes in the rate of the penetration of daylight occurred with depth down to levels of 50 meters or more. Another object of the investigation was to learn how closely simple Secchi Disc determinations agreed with the transparency values obtained from the more elaborate Photronic cell photometer. Since Secchi disc measurements require only a few minutes, they might be used to supplement the more time-consuming photometer measurements if good agreement were found.

PROCEDURE

At every station a standard series of measurements was made by comparing the readings of two photometers, one of which was mounted on deck and the other lowered into the sea. Each photometer contained a Weston Photronic cell, the spectral sensitivity of which ex-

* Contribution No. 306.

* The measurements at sea were carried out by Mr. A. H. Woodcock and the calculations and graphs were prepared by Mr. D. F. Bumpus, of the Woods Hole Oceanographic Institution.

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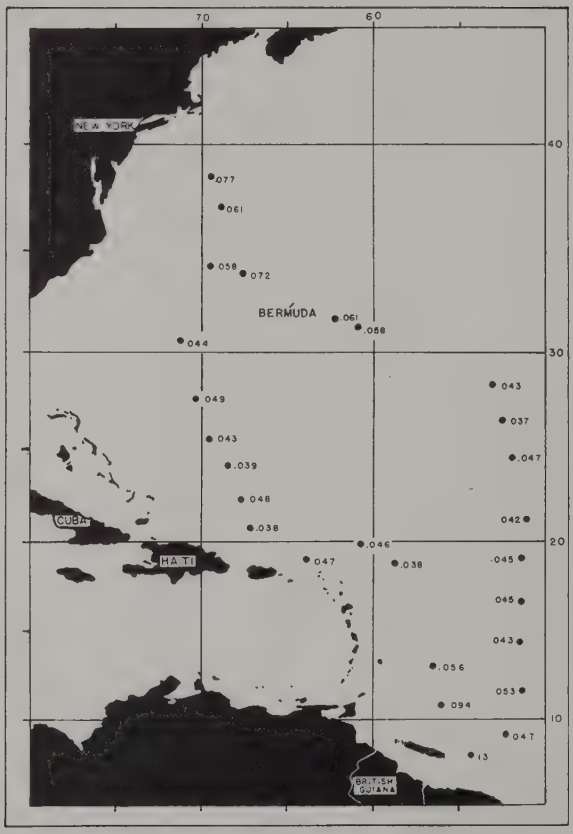

Figure 50. Location of stations where observations were made. Figures give the average value of the extinction coefficient, k, (Column 7, Table I) for range from 2 meters to greatest depth at which observation could be made (Column 6, Table I).

hibits a maximum at 5800A and drops off to 10% of the maximum at 7080A and at 3420A. A diffusing disc of opal glass was placed over each photometer but no color filter was used. In general, the same procedure was followed as in the earlier investigations of the author. All measurements were made between 10:45 a. m. and 2:45 p. m. E.S.T. At the same time that these precise determinations were

being carried out with the Photronic cells, a rough visual measure of transparency was made by lowering a Secchi disc (white disc 20 cm. in diameter) into the water and noting the depth at which it disappeared.

The 27 series of measurements with the Photronic cell photometers are summarized in Table I. In each case the range in depth over which the series extended is indicated (Column 6). The first determination was made as near the surface as circumstances permitted (usually at 2 meters) and succeeding readings were taken ordinarily at 6, 10, 15, 20, 25 and 30 meters and thereafter at every ten meters to the greatest depth at which the instrument would respond. The value of the extinction coefficient,* k, for the entire range of depth indicated for each series is given in Column 7. For the sake of uniformity, the value of the extinction coefficient down to 50 meters only has also been worked out and is presented in Column 8. Although certain differences exist in some cases between these values and the extinction coefficients for the entire range in depth, the variance is slight and the same general picture of the regional distribution of transparency is obtained from either set of data.

TRANSPARENCY CURVES

A large number of the transparency observations on this cruise were made under very unfavorable weather conditions and consequently considerable irregularity appeared among the individual measurements of each series. Nevertheless the trend of the measurements is consistent in most cases, as may be observed from the sample set of curves presented in Fig. 51. From the straightness of these semi-logarithmic plots and from the curves for all the other series of measurements, it is learned that there was no important change in transparency with depth at any station. In other words, the water tended to be optically homogeneous in each case down to the depth to which the series extended.

Of the individual series of measurements Series 534, made February 21, 1941 at Station 4121 (about 750 miles Southeast of Bermuda), is of particular interest because of the extremely great transparency it represents. The average value of the extinction coefficient over the range 2 to 133 meters was $k = .037$ and individual segments of the curve give an even lower value. The Secchi Disc depth was 41 meters at this station. The lowest value obtained previously with a photometer of similar, though not identical, spectral sensitivity was $k = .042$

* Extinction coefficient $= k$ in the equation $I/I_0 = e^{-kL}$ where the light is reduced from I_0 to I by a stratum L meters thick.

TABLE I—Summary of Transparency Measurements with Photronic Photometers and Comparison with Secchi Disc Determinations

1	2	3	4	5	6	7	8	9	10
Series Number	*Atlantis Station*	*Position Latitude*	*Position Longitude*	*Date 1941*	*Depth Range for Series*	*Extinction coefficient, k*	*Ext. Coeff. for range 2–50 m.*	*Max. depth of visibility of Secchi Disc*	*% surface light at Secchi Disc depth*
530	4108	33° 51′ N	67° 37′ W	Jan. 19	6–85 m.	.072	.068	19 m.	26%
1	4111	31° 40′	62° 16′	24	1–127	.061	.066	(40)	(4.3)
2	4112	31′ 12°	60° 55′	25	2–65	.058	.059	23	15
3	4119	28° 17′	53° 09′	28	2–102	.043	.049	39	17
4	4121	26° 26′	52° 34′	29	2–133	.037	.038	41	11
5	4123	24° 31′	51° 57′	30	2–85	.047	.046	32	15
6	4127	21° 09′	51° 03′	Feb. 1	2–126	.042	.042	37	15
7	4129	19° 00′	51° 18′	2	2–101	.045	.044	39	13
8	4131	16° 39′	51° 26′	3	2–77	.045	.044	35	23
9	4133	14° 21′	51° 27′	4	2–66	.043	.043	35	19
540	4135	11° 34′	51° 20′	5	2–77	.053	.050	38	15
1	4137	9° 02′	52° 17′	6	2–85	.047	.055	40	9.3
2	4139	7° 53′	54° 19′	7	2–55	.13	.13	13	18
3	4141	10° 46′	56° 01′	8	2–47	.094	.092	(36)	(3.6)
4	4143	13° 01′	56° 33′	9	2–50	.056	.059	21	18
5	4147	18° 49′	58° 47′	11	2–52	.038	.040	43	13
6	4149	19° 51′	60° 47′	12	2–46	.046	.048	34	13
7	4151	18° 59′	63° 54′	13	2–74	.047	.042	33	15
8	4155	20° 42′	67° 11′	21	2–109	.038	.036	47	12
9	4157	22° 16′	67° 45′	22	2–69	.048	.050	33	15
550	4159	24° 06′	68° 25′	23	2–99	.039	.040	37	20
1	4161	25° 29′	69° 34′	24	2–80	.043	.035	36	19
2	4163	27° 35′	70° 19′	25	2–85	.049	.048	33	15
3	4167	30° 36′	71° 14′	27	2–67	.044	.045	30	17
4	4170	34° 17′	69° 26′	Mar. 3	2–83	.058	.058	31	11
5	4172	37° 03′	68° 52′	6	2–95	.061	.072	27	8.0
6	4174	38° 30′	69° 35′	7	2–86	.077	.079	21	9.6

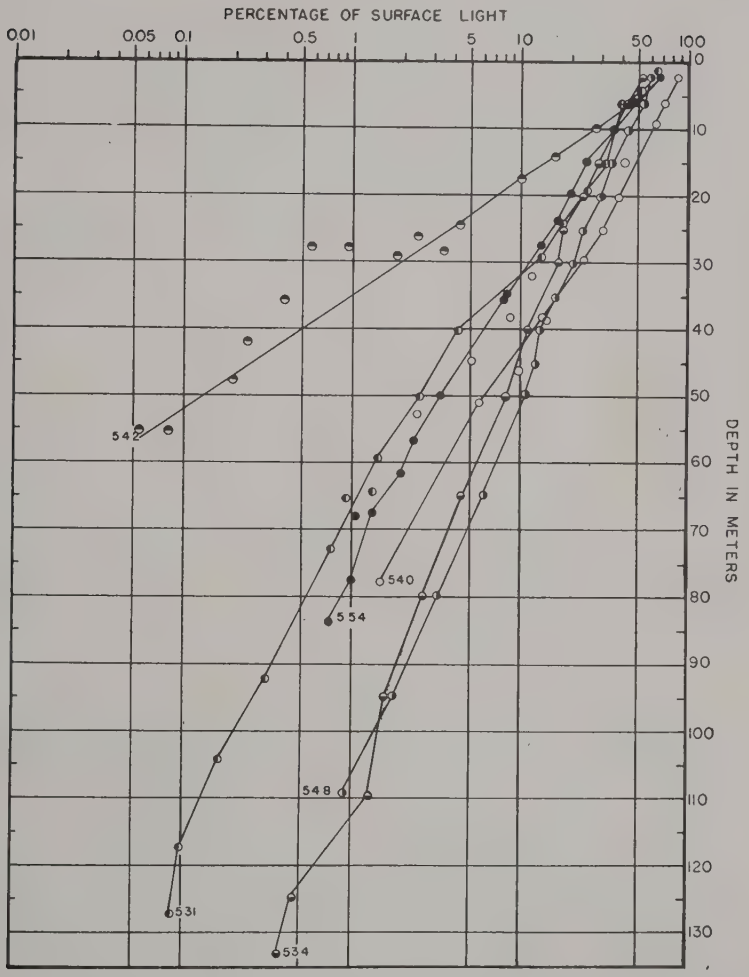

Figure 51. Sample set of curves showing percentage of light incident on the surface which reaches the depths indicated (semi-logarithmic plot). Series number appears at end of each curve. For complete data see Table I.

for the range 2 to 185 meters ($k = .038$ for the range 95–185 meters) in the Cayman Sea, west of Jamaica (Clarke, 1938, p. 90). In the present investigation average values for the extinction coefficient which were almost as low as in Series 534 were obtained at three other stations (See Fig. 50). The greatest value for the Secchi Disc determination was at Station 4155 (about 130 miles northeast of Puerto Rico) where the disc was seen at 47 meters. On this occasion, calm weather allowed the disc to sink without departing appreciably from the vertical and made possible an unusually precise determination with the Photronic photometer (Series 548, $k = .036$ for range 2–50 meters). The greatest previous depth for the visibility of the Secchi Disc of which I am aware is 40 meters for Crater Lake, Oregon (Hasler, 1938).

REGIONAL DISTRIBUTION OF TRANSPARENCY

The observations made across the North Equatorial Current from Latitude 29° N. to Latitude 14° N. between Longitude 51° W. and 53° W. yielded low values for the average extinction coefficient, all of which fell between $k = .037$ and .047. Similarly, low values, ranging from .038 to .049, were obtained for measurements made from a point about 200 miles off Antigua northwestward in the water of the Antilles Current to a point about 360 miles southwest of Bermuda. We may therefore conclude that this region lying south of Bermuda and north and west of the Antilles is one of very high and relatively uniform transparency. In fact, the values obtained represent the clearest ocean water known.

Farther to the south the transparency is somewhat reduced and at the southernmost station in the Guiana Current about 100 miles off the coast of Guiana the extinction coefficient rose to $k = .13$. At this point and at the next station to the northwest the clearness of the water was distinctly less than at the stations farther offshore.

At the stations immediately southeast of Bermuda and at those northwest of the Island and toward New York, water of intermediate transparency was encountered. The values of the extinction coefficient ranged from $k = .058$ to .077 in this region. These values and those for the larger area to the south agree well with the few measurements carried out during earlier investigations near these regions.

COMPARISON WITH SECCHI DISC MEASUREMENTS

The Secchi Disc measurements (Table I, Column 9) may be compared graphically with the values for the extinction coefficients for

the depth range of 2 to 50 meters as determined by the Photronic cell photometers in Fig. 52. It is seen that the majority of measurements fall between $k = .040$ and .050 and that these are accompanied by Secchi Disc values lying between 30 meters and 40 meters. Higher extinction coefficients are correlated with lower Secchi Disc values. However, the scatter in the correlation is considerable and it is de-

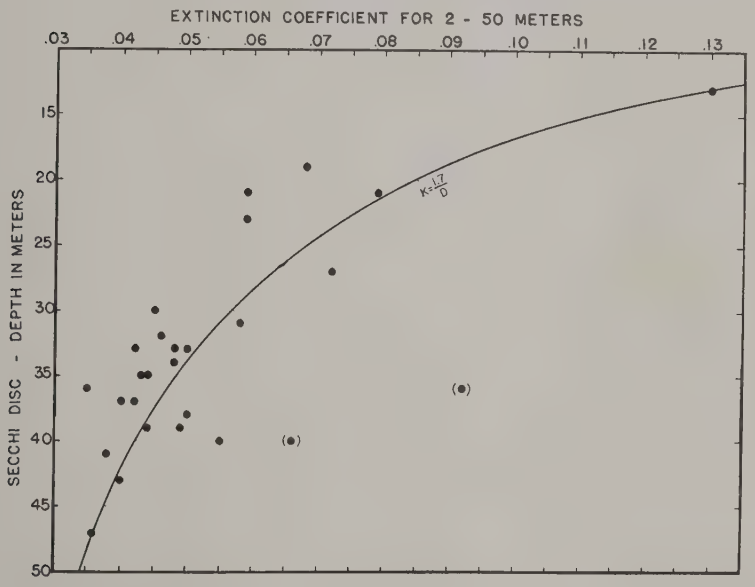

Figure 52. Correlation chart of the Secchi disc determinations and the extinction coefficients from the Photronic photometer measurements for range 2 to 50 meters. Curve of the equation $k = 1.7/D$ has been superimposed.

sirable to ascertain whether the lack of agreement is due primarily to the relative crudity of the Secchi Disc measurement or to some other cause.

Measurements with the Secchi Disc can ordinarily be repeated with a variation of less than one meter but during the present cruise unfavorable weather conditions were encountered at a large number of the stations. The large size of the waves and the irregularity of the light reflected from the surface interfered seriously with the determinations. (The use of a tube passing beneath the surface through which the investigator may observe the disc is indicated for

future work.) Furthermore, the drift of the ship was such that in many cases the cord supporting the disc acquired an angle of 30° or more to the vertical. Although the vertical depth of the disc could be calculated (if the cord be assumed to have been straight), as is always done in the case of the Photronic photometer, this procedure would not give a correct value for the limit of visibility since the path of the light *from the disc to the observer's eye* follows the angle of the supporting cord. In view of this complication it did not seem worth while to attempt a correction for the angle of stray and the values given are the total length of cord from the surface to the disc.

Errors of measurement may therefore account for a part, or all, of the irregularities in the correlation of the Secchi Disc measurements and the extinction coefficients. Another possible explanation, which must be borne in mind, is the fact that in two cases in which the actual amount of light reaching a certain depth is identical (as measured by the Photronic cell photometer), the relative parts played by the processes of *scattering* and true *absorption* may be very different. In the situation in which scattering is greater, the light from the Secchi Disc would be more highly diffused and hence the disc would be less easily recognized from the surface. Such a condition has been reported for lakes (Sauberer, 1939). In the case of the ocean, this possibility, that there may be important differences in the relative roles of scattering and absorption from place to place in addition to the already recognized variation in the "total" rate of light extinction should be carefully tested in as many situations as possible.

The relation between the value of k, the extinction coefficient, as determined by a photometer and D, the depth for the limit of visibility of the Secchi Disc was found by Poole and Atkins (1929) on the basis of their measurements off Plymouth, England, in water of lower transparency ($k = .088$ to $.203$) to be described roughly by the equation $k = 1.7/D$. A curve expressing this relationship has been drawn on the correlation graph (Fig. 52). It is seen that this curve agrees remarkably well with the average position of the points. If the two observations represented by points within parentheses are rejected as probably in error because of their wide divergence, then the remaining points fall satisfactorily within a band of moderate width, the axis of which is described by the above equation.

The magnitude of the illumination at the depth at which the Secchi Disc is just visible is of interest and has been determined from the curves of light penetration at each station. This may be given as

percentage of light incident at the surface as experience has shown (cf. Poole and Atkins, 1929) that differences in the value of daylight may be neglected if measurements are made near the middle of the day (as was the case in this investigation). The percentage of the light at the surface which existed at the depth obtained for the Secchi Disc appears in Column 10 of Table I. It is observed that the illumination varies from 8.0% to 26% (omitting the two questionable observations) with an average of 15.2%. These values agree very closely with those of Poole and Atkins (1929) who reported a variation for his set of 14 series of measurements from 9.6% to 22.6% with an average of 15.8%. This range in the percentage illumination and the width of the band in the correlation graph (Fig. 3) are a measure of the extent to which the photometric and the visual methods of transparency measurement agree. Further work is called for to determine how much of the discrepancy is due to error of measurement, and how much to differences in the optical properties of the water.

SUMMARY

1. Twenty-seven series of light penetration measurements were made with Photronic cell photometers to depths as great as 133 meters in the southwestern section of the North Atlantic Ocean.

2. The water exhibited no important change in transparency with depth. A minimum average value for the extinction coefficient of $k = 0.037$ and a maximum depth for the Secchi Disc of $D = 47$ meters were observed.

3. The region south of Bermuda and north and west of the Antilles was found to contain the clearest ocean water known and to be relatively homogeneous in respect to transparency. Off the coast of Guiana a sharp drop in transparency was encountered. To the southeast and to the northwest of Bermuda, the water is very clear but less so than farther to the south.

4. A comparison of the Photronic photometer measurements with the Secchi disc determinations shows in general good agreement with the relation, $k = 1.7/D$, reported by Poole and Atkins. At the depth of disappearance of the disc the illumination averaged 15% of the light incident at the surface. Individual variations suggest the possibility that important changes in the relative effects of scattering and absorption may occur in ocean waters.

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Report of the year 1940

THE WOODS HOLE OCEANOGRAPHIC INSTITUTION

REPORT FOR THE YEAR
1940

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I. TRUSTEES

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HENRY L. SHATTUCK, 50 Federal Street, Boston, Mass.
T. WAYLAND VAUGHAN, 3333 P Street, Washington, D. C.

To serve until 1943

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E. G. CONKLIN, Princeton University, Princeton, N. J.
ROSS G. HARRISON, Yale University, New Haven, Conn.
THE HYDROGRAPHER (Captain G. S. Bryan), U. S. Hydrographic Office, for the time being, Washington, D. C.
FRANK R. LILLIE, 5801 Kenwood Avenue, Chicago, Ill.
HARLOW SHAPLEY, Harvard University, Cambridge, Mass.

To serve until 1942

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THOMAS BARBOUR, Museum of Comparative Zoölogy, Cambridge, Mass.
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FRANK B. JEWETT, 195 Broadway, New York, N. Y.
ALBERT E. PARR, Bingham Oceanographic Foundation, New Haven, Conn.
ELIHU ROOT, JR., 31 Nassau Street, New York, N. Y.

To serve until 1941

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MARION EPPLEY, The Eppley Laboratory, Inc., Newport, R. I.
LAMAR R. LEAHY, U. S. Navy, Retired, Catherine Street, Newport, R. I.
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THE DIRECTOR (Admiral L. O. Colbert), U. S. Coast & Geodetic Survey, for the time being, Washington, D. C.
B. W. ST. CLAIR, 10 Arrow Street, Cambridge, Mass.

Ex Officio

COLUMBUS O'D. ISELIN, Woods Hole Oceanographic Institution, Woods Hole, Mass.
LAWRASON RIGGS, JR., 120 Broadway, New York, N. Y.

OFFICERS

HENRY B. BIGELOW, President of the Corporation, Museum of Comparative Zoölogy, Cambridge, Mass.
LAWRASON RIGGS, JR., Treasurer, 120 Broadway, New York, N. Y.
COLUMBUS O'D. ISELIN, Clerk of the Corporation, Woods Hole Oceanographic Institution, Woods Hole, Mass.

II. MEMBERS OF THE CORPORATION

Charles Francis Adams, 15 State Street, Boston, Mass.
Thomas Barbour, Museum of Comparative Zoölogy, Cambridge, Mass.
Henry B. Bigelow, Museum of Comparative Zoölogy, Cambridge, Mass.
Isaiah Bowman, Johns Hopkins University, Baltimore, Md.
Vannevar Bush, 1530 P Street, N.W. Washington, D. C.
The Commandant (Admiral R. R. Waesche), U. S. Coast Guard, for the time being, Washington, D. C.
E. G. Conklin, Princeton University, Princeton, N. J.
The Director (Admiral L. O. Colbert), U. S. Coast & Geodetic Survey, for the time being, Washington, D. C.
Benjamin M. Duggar, University of Wisconsin, Madison, Wis.
Marion Eppley, The Eppley Laboratory, Inc., Newport, R. I.
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Alexander Forbes, Harvard Medical School, Boston, Mass.
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A. G. Huntsman, University of Toronto, Toronto, Canada.
The Hydrographer (Captain G. S. Bryan), U. S. Hydrographic Office, for the time being, Washington, D. C.
Columbus O'D. Iselin, Woods Hole Oceanographic Institution, Woods Hole, Mass.
Frank B. Jewett, 195 Broadway, New York, N. Y.
Lamar R. Leahy, U. S. Navy Retired, Catherine St., Newport, R. I.
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T. H. Morgan, California Institute of Technology, Pasadena, Calif.
Albert E. Parr, Bingham Oceanographic Foundation, New Haven, Conn.
Alfred C. Redfield, Harvard University, Cambridge, Mass.
Lawrason Riggs, Jr., 120 Broadway, New York, N. Y.
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B. W. St. Clair, 10 Arrow Street, Cambridge, Mass.
Harlow Shapley, Harvard University, Cambridge, Mass.
Henry L. Shattuck, 50 Federal Street, Boston, Mass.
T. Wayland Vaughan, 3333 P Street, Washington, D. C.

III. REPORT OF THE TREASURER

To The Members and Trustees of the
Woods Hole Oceanographic Institution

Gentlemen:

The accounts for the year 1940 have been audited by Messrs. Stagg, Mather & Hough, public accountants.

During the year bonds costing $221,006.50 were redeemed at a net profit (after adding the applicable reserve for amortization) of $2,087.23 and $6,000.00. Commonwealth Edison were converted into 240 shares of common stock.

There was invested $111,070.00 in bonds and $92,546.43 in stocks.

The Special Income Account in which extra dividends are placed increased by $3,847.66.

Out of the appropriation of $4,800.00 for the reserve for periodic replacements a shipyard bill of $3,687.00 was paid, and the balance of $1,113.00 has been added to the Fund.

The Institution is working on two projects for the Government. It received $3,638.33 on Project No. 1 and spent $3,632.68. The credit balance of $5.65 appears in the balance sheet as a reduction of the accounts receivable.

In Project No. 2 the disbursements including accounts payable were $7,638.15, no part of which had been received at the end of the year, nor are any items included in expenses.

Under the contract for Project No. 2 there was receivable for share of expenses of boats and overhead $791.67 per month from October 1, 1940. No part of this was paid in the year and is not included as a receivable. It will be included in 1941 as a receipt.

The gross income on the securities in the Endowment Fund was about .0448 of the cost of the securities and .0472 of their market value at the end of the year.

The total expenses (not including the disbursements for the Government) exceeded the budget by $1,716.66 but were under receipts by $7,267.09.

Summaries of the balance sheet and comparative income and expense statements for 1940 and 1939 appear on pages 6 to 8.

Respectfully submitted,

Lawrason Riggs, Jr.,
Treasurer

BALANCE SHEET

ENDOWMENT FUND ASSETS

	Quoted Market Value		
Endowment fund assets:			
Bonds (less reserve for amortization of bond premiums $5,859.99)	$1,177,027.08	$1,205,307.26	
Stocks	$1,136,382.25	1,224,637.80	
Cash		23,275.00	$2,453,220.06
Reserve fund assets:			
Bonds	$ 8,832.50	$ 8,587.50	
Stocks	13,154.50	19,099.02	
Cash		1,188.38	28,874.90
			$2,482,094.96

PLANT ASSETS

Laboratory plant:		
Land	$ 27,072.32	
Buildings	323,213.12	
Laboratory equipment	21,361.93	
Crew room equipment	557.95	
Library	11,900.00	$ 384,105.32
Ship "Atlantis":		
Construction	$ 218,674.47	
Equipment	27,298.50	245,972.97
Small boat and equipment		6,570.55
		$ 636,648.84
Depreciation fund assets (for periodic replacements):		
Bonds (quoted market value $31,765.00)	$ 32,731.25	
Cash (including $1,113.00 due from current fund cash)	3,596.35	36,327.60
		$ 672,976.44

CURRENT ASSETS

Current Funds Cash	$ 13,431.84	
Less—Due to special and depreciation funds	4,351.00	$ 9,080.84
Special income assets:		
Investments		
Bonds (quoted market value $23,172.50)	$ 22,797.50	
Stocks (quoted market value $1,107.44)	1,370.38	
Cash (including $3,238.00 due from current fund cash)	4,526.97	28,694.85
Accounts receivable—Navy projects No. 1 and 2	$ 7,632.50	
Interest accrued at date of acquisition on bonds purchased	487.09	8,119.59
		$ 45,895.28
Total assets		$3,200,966.68

DECEMBER 31, 1940

ENDOWMENT FUNDS

Endowment fund—General	$2,000,000.00	
Endowment—for upkeep of plant	419,419.96	
	$2,419,419.96	
Add—Accumulated net gain on securities called or sold	33,800.10	$2,453,220.06
Reserve fund	$ 23,395.57	
Add—Accumulated reserve fund income	5,479.33	28,874.90
		$2,482,094.96

PLANT FUND

Plant fund—General	$ 607,642.13	
Plant fund reserve—Transferred in prior years from current surplus	29,006.71	$ 636,648.84
Reserve for periodic replacements		36,327.60
		$ 672,976.44

CURRENT LIABILITIES AND SURPLUS

Accounts payable		$ 8,511.09
Capital surplus:		
Balance at December 31, 1939	$ 30,117.10	
Add—Excess of income over expenses for the year ended December 31, 1940	7,267.09	37,384.19
		$ 45,895.28
Total funds, current liabilities and surplus		$3,200,966.68

STATEMENT OF INCOME FROM ENDOWMENT FUND INVESTMENTS AND FROM CURRENT ASSETS, AND EXPENSES APPLICABLE THERETO, INCLUDING EXPENDITURES FOR PERMANENT PLANT ADDITIONS

FOR THE YEARS ENDED DECEMBER 31, 1940 AND DECEMBER 31, 1939

Income:						
From endowment funds:						
Interest (including in 1940 special income of $473.39)		$55,276.99			$60,174.44	
Dividends (including in 1940 special income of $3,363.88)		60,258.14	$115,535.13		53,942.52	$114,116.96
Less—Custodian fees and expenses			1,551.38			1,508.94
			$113,983.75			$112,608.02
Contributions received for operating expenses			—			1,633.26
Total Income				$113,983.75		$114,241.28
Expenses:	*Budget 1940*					
Upkeep of plant:						
Upkeep of Buildings and Grounds	$ 6,932.00	$ 7,634.94			$ 7,015.20	
Upkeep of "Atlantis"	7,500.00	10,118.80			9,423.10	
Upkeep of "Asterias"	150.00	182.03			833.91	
Insurance	5,833.00	5,889.89			5,658.17	
Depreciation	4,800.00	4,800.00			4,800.00	
	$ 25,215.00		$ 28,625.66			$ 27,730.38
Operating Expenses:						
Operation of "Atlantis"	$ 31,300.00	$30,406.79			$33,640.26	
Operation of "Asterias"	850.00	671.53			807.32	
Scientists' salaries	26,700.00	26,484.58			26,369.87	
Scientific supplies and equipment	6,000.00	4,950.69			6,013.52	
Traveling expenses	600.00	459.97			1,149.79	
Publications	3,000.00	2,714.71			3,053.37	
Administration	7,535.00	7,603.50			7,640.45	
Amortization of bond premiums	1,600.00	2,634.21			2,242.95	
Contribution to retirement fund	1,550.00	1,493.64			1,576.92	
Miscellaneous (staff meetings and "Anton Dohrn" expenses)	50.00	71.38			—	
	$ 79,185.00		$ 77,491.00			$ 82,494.45
Total expenses	$104,400.00		$106,116.66			$110,224.83
Expenditures for permanent plant additions:						
Additions to library	600.00		600.00		600.00	
	$105,000.00			106,716.66		110,824.83
Excess of income over expenses				$ 7,267.09		$ 3,416.45

IV. ELEVENTH ANNUAL REPORT OF THE DIRECTOR FOR THE YEAR 1940

BY C. O'D. ISELIN

Our program of research has not remained unaffected by the war in Europe. It is of course no longer advisable to send the "Atlantis" too far from this coast, but so far this restriction has not been a serious one. Because of the increasing demand for trained meteorologists two of our staff have been asked to take on heavier teaching loads, while several others may at any time be called for active duty with the Army or Navy. Thus at a time when there is an increased demand for our cooperation with various governmental research agencies, we are faced with the temporary loss of some of our trained personnel, both on the "Atlantis" and in the laboratory.

During the past year the Institution's contract with the Bureau of Ships of the Navy Department has been gradually increased so that now a considerable part of our bacteriological and biological effort is directed towards a study of marine fouling organisms. Finally, the decision of the Trustees at their meeting in August to offer our facilities to the government has led to a contract with the National Defense Research Committee and to a considerable expansion of both equipment and personnel.

While these developments were taking place our ordinary oceanographic program was at first only slightly interfered with, but since October the entire time of the "Atlantis" and of several of our staff has been required for the new undertakings.

Equipment

There have been two important additions to our equipment during the past year. First, the Carnegie Institution of Washington turned over to us unconditionally their 70 ft. power boat "Anton Dohrn." While it will be necessary to make some alterations on deck to outfit her for these latitudes, her design and strength of construction are such that she is quite capable of extended offshore voyages during the summer months. Second, a small machine shop has been set up in the basement, so that for instrumental development and repairs we are no longer dependent on commercial companies.

In February the "Atlantis" passed her required Lloyd's survey. This was a complete hull and engine survey, the most thorough we have yet had to undergo. More recently a new bilge and fire pump was installed and in November much of the electric wiring of the main trawl winch was renewed.

Three new bottom sampling devices have been bought: the first, a heavily weighted tube to take the place of the Piggot gun; the second, an ordinary $2\frac{1}{2}$ cu. ft. clam shell bucket of commercial design; and the third, a new Stetson sampler to replace one that was lost.

Minor items of new scientific equipment include 4 reversing thermometers and 3 plankton samplers.

Accidents

In heavy gales last winter the forstaysail boom on the "Atlantis" broke in two and the mizzen boom became badly cracked. A new boom for the jib was made locally and the mizzen boom was very skillfully repaired so that it is now considerably stronger than when new.

Loans

We have borrowed two continuous plankton recorders from Professor A. C. Hardy of Hull, England. These are the first such instruments to be used in this country and they will greatly advance our plankton program.

Library

Our contribution to the library of the Marine Biological Laboratory was the same this year as last, namely, $600. This sum was spent as follows: 39 current journals and monographs were subscribed to; 12 books were purchased; 2 back sets were completed and 2 partially completed; 56 volumes were bound. In addition, 65 current journals were received in exchange for our publications and 11 as gifts. About 305 additional journal numbers and reprints were donated to the library by members of our staff.

Personnel

During the year three new staff appointments were made by vote of the Executive Committee: Dr. Gordon A. Riley as Marine Biologist, Dr. Bostwick H. Ketchum as Associate in Marine Biology and Dr. William Maurice Ewing as Associate in Submarine Geology.

By the end of the year the following assistants and technicians were working specifically under the National Defense Research Committee's contract: Carlyle A. Crecelius, Robert J. McCurdy III, Gilbert Oakley, Jr., Allyn C. Vine and J. Lamar Worzel.

Fellowship holders who worked at the laboratory during the summer were: Dr. A. A. Abramowitz, Mr. John Dobson, Dr. Frederick Phleger, Mr. Andrew P. Stergion, Dr. George Wald and Mr. George C. Whiteley, Jr., Dr. Clinton M. Osborn, Miss Frances L.

Parker, Dr. Theodor von Brand and Dr. John H. Welsh worked under special grants.

There were four assistants to the various staff members and four volunteer workers. Seventeen institutions were represented during the year in the laboratory or on cruises of the "Atlantis." In all about 85 individuals, in addition to the crew of the "Atlantis," have taken part in our program.

Travel

Since September Dr. H. R. Seiwell has been on a visit at the Scripps Institution of Oceanography.

Publications

Number 4 of Volume VII and Number 1 of Volume VIII of "Papers in Physical Oceanography and Meteorology" appeared.

The following contributions were published during the year:

No. 62. H. R. Seiwell. Time Variability of Hydrographic Elements Determining the Dynamic Situation in the Western North Atlantic. Proc. Am. Philos. Soc., Vol. 82, No. 3, pp. 369–394. 1940.

No. 72. James B. Lackey. Some New Flagellates from the Woods Hole Area. The Amer. Midland Nat., Vol. 23, No. 2, pp. 463–471. 1940.

No. 187. J. L. Hough. Sediments of Buzzards Bay, Massachusetts. Journ. Sedimentary Petrology, Vol. 10, No. 1, pp. 19–23. 1940.

No. 215. Floyd M. Soule. Oceanography. Excerpt from International Ice Observation and Ice Patrol Service in the North Atlantic Ocean, Season of 1938. U. S. Coast Guard Bull., No. 28, pp. 113–173. 1940.

No. 231. Charles W. Hock. Decomposition of Chitin by Marine Bacteria. Biol. Bull., Vol. 79, No. 1, pp. 199–206. 1940.

No. 235. R. B. Montgomery. Observations of Vertical Humidity Distribution Above the Ocean Surface and their Relation to Evaporation. Papers in Physical Oceanography and Meteorology, Vol. VII, No. 4, pp. 1–30. 1940.

No. 237. H. R. Seiwell. Anchoring Ships on the High Seas. U. S. Naval Inst. Proc. Vol. 66, No. 12, Whole No. 454, pp. 1733–1740. 1940.

No. 239. Henry B. Bigelow. Medusae of the Templeton Crocker and Eastern Pacific "Zaca" Expeditions, 1936–1938. Zoologica, Vol. XXV (Part 3), pp. 281–321. 1940.

No. 241. George L. Clarke. Comparative Richness of Zoöplankton in Coastal and Offshore Areas of the Atlantic. Biol. Bull., Vol. LXXVIII, No. 2, pp. 226–255. 1940.

No. 242. C. P. Winsor and G. L. Clarke. A Statistical Study of Variation in the Catch of Plankton Nets. Sears Found. Jour. Mar. Res., Vol. III, No. 1, pp. 1–34. 1940.

No. 245. R. B. Montgomery. The Present Evidence on the Importance of Lateral Mixing Processes in the Ocean. Bull. Am. Meteorol. Soc. Vol. 21, No. 3, pp. 87–94. 1940.

No. 246. A. A. Abramowitz, F. L. Hisaw, E. Boettiger and D. A. Papandrea. The Origin of the Diabetogenic Hormone in the Dogfish. Biol. Bull., Vol. LXXVIII, No. 2, pp. 189–201. 1940.

No. 247. Clinton M. Osborn. The Experimental Production of Melanin Pigment on the Lower Surface of Summer Flounders *Paralichthys dentatus*. Proc. Nat. Acad. Sci., Vol. 26, No. 3, pp. 155–161. 1940.

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Field Work

Operations of "Atlantis" for the year 1939:

Cruise 93: January 3–12; Biological Survey of Georges Bank.

Cruise 94: January 17–March 17; Southward to Gulf Stream waters off Jacksonville, Florida.

Cruise 95: March 21–April 3; Biological Survey of Georges Bank.

Cruise 96: April 17–27; Biological Survey of Georges Bank.

Cruise 97: May 7–16; Biological Survey of Georges Bank.

Cruise 98: May 28–June 8; Biological Survey of Georges Bank.

Cruise 99: June 12–14; Testing the bathythermograph.

Cruise 100: June 18–27; Biological Survey of Georges Bank.

Cruise 101: July 9–17; Deep anchor station south of Montauk Point.

Cruise 102: July 22–27; Seismic experiments in deep water south of Montauk Point.

Cruise 103: July 31–Aug. 6; Southward along the continental slope to Virginia for bottom samples and bottom dredging.

Cruise 104: August 20–29; Survey of an eddy at the edge of the Gulf Stream.

Cruise 105: September 3–8; Anchor station off Georges Bank.

Cruise 106: September 17–28; Seismic experiments in deep water south of Montauk Point.

Cruise 107: October 22–November 1; Gulf Stream section.

Cruise 108: November 21–December 3; Gulf Stream section.

Cruise 109: December 11–13; Testing the bathythermograph.

Summary of observations:

Total distance sailed	14,221
Number of days at sea	226
Deep hydrographic stations	50
Shallow hydrographic stations	298
Bathythermograph lowerings	450
Serial temperature lowerings of internal waves	65
Plankton hauls	733
Blake trawl tows	9
Bottom samples	30

"Asterias" was in use during the summer months for the usual short trips near Woods Hole and in Massachusetts Bay. William McCulley was in charge, assisted by W. K. Maas.

Scientific Program

Signs are multiplying that the recent expansion in physical oceanography may be in danger of running its course. It has become increasingly clear that the technique of water-bottles and reversing thermometers will not answer some of the important problems in which we are most interested. Thus during the last year or two we have been feeling out new approaches. One promising method depends on combining the bathythermograph with a pressure-operated, multiple, water sampling device. Such an instrument has been built by Dr. Spilhaus and operates successfully while the "Atlantis" is at full speed.

While we have great hopes that this instrument will lead to a better understanding of lateral frictional forces and small scale mixing processes, there are other phenomena which will perhaps require different methods. In shallow and weak currents the circulation theorem leads to very unsatisfactory results and it is becoming more and more evident that for hydrographic work on the continental shelf we need a method of measuring mass cross current transfer.

This whole problem has been emphasized by the six surveys of Georges Bank which were made during the past year, and the difficulties we are encountering in this investigation illustrate very nicely the necessity for team-work in oceanographic research.

The Georges Bank program, begun in September 1939, was conceived primarily as a biological project. We undertook to study the factors influencing the survival of haddock during their planktonic stages. While the program is centered around the young haddock, it need not be considered a fisheries investigation. The dangers which

the haddock eggs must survive are typical of those which beset many other groups of marine animals and of course in sampling the haddock eggs we must also sample the whole plankton population. It was decided to pay special attention to the haddock because as a nursery ground for these fish Georges Bank can be considered as a unit. Moreover, in the statistics of the trawler fishery we will have the best sort of information concerning the relative success of the various year classes now being studied in their planktonic stages. Finally, here is an investigation which if repeated for a number of years might throw light on one of the most interesting of oceanographic problems. Is the great variability from year to year in the reproduction of many marine forms mainly due to biological or to physical factors? Are the haddock eggs particularly delicate, are most of them destroyed by enemies or does the success of each year class depend mainly on the current system prevailing over the spawning grounds? The physical oceanographers of course favor a strictly physical explanation, while the biologists are inclined to hunt for biological factors.

To properly analyze the extensive series of plankton hauls made last spring on Georges Bank in the course of the six surveys it is necessary to consider the variations in the currents and to learn whether or not a considerable part of the population of the bank waters was swept off the bank. A preliminary study of the hydrographic data only emphasizes how little the ordinary observations can tell us about the all important lateral movements. In short, the main goal of this biological program will probably not be achieved unless the physical oceanographers can devise a new approach to the problem of circulation in shallow areas.

The Georges Bank surveys are representative of one method of marine biology. Another approach, and one which in the end is bound to yield results, is based on a long accumulation of quantitative records. Dr. Sears has taken charge of this aspect of our plankton program. Already about 1700 cards have been filled out and filed away. About 500 more tows await analysis. We will then have in convenient form information on all available quantitative plankton hauls off this coast since 1929. It is likely that Dr. Sears can show that hauls from certain key stations are representative of the production over wide areas. Thus before long it may be possible to follow the variations in productivity from year to year by means of relatively few tows. The ultimate aim of course is to correlate the changes in the plankton with the variations in the fisheries.

I will mention only one other line of work in which we have been having some success, because it illustrates very nicely how careful

observations at sea can sometimes provide a clue which will open up a whole new field. For some time it has been clear that those who have been developing the theory to account for the transfer of energy between the winds and the sea surface have of necessity had to oversimplify the problem. Then a few years ago Dr. Langmuir called our attention to the lines of gulf weed often seen in mid-Atlantic. People have been looking at gulf weed for centuries and apparently no one ever stopped to wonder why sometimes it was scattered at random and at other times it was collected in long parallel bands extending down wind. Dr. Langmuir suggested alternating bands of convergence and divergence in the surface layer, but such a pattern of flow did not fit in with any known oceanographic theory.

Mr. Woodcock, because he spends so much time on the "Atlantis," seemed the logical person to interest himself in this question and he began to collect observations in the hope that he could correlate the behavior of the gulf weed with the strength of the wind and the distribution of temperature and salinity in the surface layer. But Mr. Woodcock was also interested in bird flight and he had been watching sea birds for several years. He had noticed that the herring gulls exhibit three distinctive flight responses and he had been collecting data on the wind velocity and on the difference in temperature between the air and the water (a measure of convection) in the hopes of explaining these various flight tactics. While watching the gulf weed and gulls day after day it occurred to him that the two phenomena were perhaps connected. When the air was unstable and when the wind was above a certain critical velocity he noticed that the soaring gulls lined up just as the gulf weed does. Apparently at times there are bands of convergence and divergence in the air, extending down wind and similar to the cells in the surface layer of the ocean which are indicated at times by the distribution of the weed. In both mediums the cellular structure is dependent on instability.

Further study of instability in the surface layer of the sea is now in progress, but it is not yet clear how important a part the wind plays in maintaining the vertical circulation. The herring gull observations indicate that there are several critical wind velocities where the whole pattern of turbulence changes in the lower layer of the atmosphere, but in the water such changes are more difficult to observe. At any rate, the experience to date is a good illustration of the progress which is often made in oceanography when physics and biology proceed hand in hand.

V. STAFF

(As of December 31, 1940)

COLUMBUS O'D. ISELIN, Associate Professor of Physical Oceanography, Harvard University, and Assistant Curator of Oceanography Museum of Comparative Zoölogy; Director.

CORNELIA L. CAREY, Assistant Professor of Botany, Barnard College; Associate in Marine Bacteriology.

GEORGE L. CLARKE, Associate Professor in Biology, Harvard University; Marine Biologist.

WILLIAM MAURICE EWING, Associate Professor in Geophysics, Lehigh University; Associate in Submarine Geology.

BOSTWICK H. KETCHUM, Associate in Marine Biology.

RAYMOND B. MONTGOMERY, Lecturer on Maritime Meteorology and Oceanography, Assistant Professor of Meteorology, New York University; Physical Oceanographer.

ALBERT E. PARR, Director of Peabody Museum and Curator of the Bingham Oceanographic Collection, Yale University; Associate in Oceanography.

NORRIS W. RAKESTRAW, Associate Professor of Chemistry, Brown University; Chemical Oceanographer.

ALFRED C. REDFIELD, Professor of Physiology, Harvard University; Associate in Marine Biology.

CHARLES E. RENN, Tutor in Biology and Instructor in Sanitary Engineering, Harvard University; Associate in Marine Bacteriology.

GORDON A. RILEY, Marine Biologist, Yale University; Marine Physiologist.

C.-G. ROSSBY, Professor of Meteorology, Massachusetts Institute of Technology, and Assistant Chief, U. S. Weather Bureau, Washington, D. C.; Associate in Physical Oceanography.

MARY SEARS, Instructor in Zoölogy, Wellesley College; Planktonologist.

H. R. SEIWELL, Physical Oceanographer.

FLOYD M. SOULE, Principal Physical Oceanographer, U. S. Coast Guard; Associate in Physical Oceanography.

ATHELSTAN F. SPILHAUS, Associate Professor of Meteorology, Chairman of the Department of Meteorology, New York University; Physical Oceanographer.

HENRY C. STETSON, Research Associate in Paleontology, Museum of Comparative Zoölogy; Submarine Geologist.

SELMAN A. WAKSMAN, Microbiologist, New Jersey Agricultural Experiment Station; Marine Bacteriologist.

EDMOND E. WATSON, Assistant Professor of Physics, Queen's University; Physical Oceanographer.

DEAN F. BUMPUS, Biological Technician.

CARLYLE A. CRECELIUS, Instrument maker.

SIDNEY C. T. HSIAO, Technician in Physical Oceanography.

ROBERT J. MCCURDY, III, Physical Technician.

GILBERT OAKLEY, Observer.

ELIZABETH ORR, Chemical Technician.

HELEN F. PHILLIPS, Secretary to the Director.

ALLYN C. VINE, Physicist.

Charles M. Weiss, Bacteriological Technician.
Alfred H. Woodcock, Oceanographic Technician.
J. Lamar Worzel, Physical Technician.

William C. Schroeder, Business Manager.
Ethelyn T. Bird, Secretary.
William Schroeder, Superintendent of Buildings and Grounds.

APPENDIX

Reports of progress by investigators working at the Institution during 1940.

MOULTING IN BLUE CRABS

A. A. ABRAMOWITZ

Removal of both eyestalks, or of the anterior half of both eyestalks resulted in a definite acceleration of moulting. Within the experimental period, all operated animals moulted (some moulted twice) while only a few (twenty per cent) of the control animals moulted. Due to the extreme paucity of animals (the total number obtained all summer was twenty-six) this conclusion in relation to its commercial possibilities should be regarded only as tenative until several large scale experiments can be run.

PRODUCTIVITY OF GEORGES BANK

GEORGE L. CLARKE

An investigation has been begun of the steps in the biological cycle which underlie the productivity of Georges Bank. This bank is an important fishing ground equal in size to the state of Massachusetts and lying east of Cape Cod. During the past year seven cruises were made to Georges Bank and on each occasion a net-work of 21 to 52 stations were occupied over the area. At each station the following work was done: (1) hydrographic measurements for temperature and salinity; (2) transparency measurements; and (3) zoöplankton hauls with the plankton sampler for the smaller organisms and with stramin nets for the larger organisms. Preliminary tests were made for extensive dredging operations over the bank for the investigation of the bottom organisms.

The data obtained on the seven cruises are now in the process of analysis. Preliminary inspection of the material indicates the following: An extensive diurnal vertical migration of certain elements of the plankton takes place. The center of the bank is occupied by certain characteristic species whereas other species dominate the margins of the bank. The plankton reached its lowest ebb in January and became most abundant in June. The type of plankton changed markedly with the season. The eggs of haddock, which is the most important of the commercial fish on the bank, were found in the plankton beginning in March, and their drift to the south and west could be followed until May. Great changes in the phytoplankton were observed seasonally but since no bottom-living plants were detected at any time, the latter evidently do not enter into the economy of the bank. The continu-

ation and the extension of this investigation is planned for the current year.

DEEP SEA SEISMIC METHODS AND BOTTOM PHOTOGRAPHY

W. M. EWING

During the winter on "Atlantis'" southern cruise a number of satisfactory tests of the redesigned seismic equipment were made in deep water. While the timing of the salt releases was not sufficiently dependable to enable us to secure an indisputable record of the thickness of the sediments, the fact that losses of apparatus were trivial indicated the feasibility of gasoline filled floats as a method for taking instruments to the bottom and returning them safely to the surface.

On a summer cruise, with improved salt releases, two complete oscillograph records of explosions at depths of 1800 and 2300 fathoms were finally achieved. There is now little doubt that the equipment is capable of securing a satisfactory seismic profile when the "Atlantis" is next free to resume this sort of work.

While these tests were in progress experience was also gained in the technique of bottom photography. Using flash bulbs and a camera enclosed in a glass chamber, 60 sets of pictures were obtained from the Georges Bank area in depths as great as 200 fathoms. Before the camera chamber failed, several photographs were also made at very much greater depths (2000 fathoms).

STUDIES IN PHYSICAL OCEANOGRAPHY

C. O'D. ISELIN

Further study of the tide gauge method for measuring the strength of currents has not been particularly fruitful. Mean monthly sea level at most tide gauge stations appears to be influenced so much by the local weather that no system of smoothing the data can be depended upon to give a detailed record of the changes due only to offshore currents. Favorably located stations such as Miami and Cat Cay may in the future be expected to give good results when a longer record has accumulated.

Some attention was given to the problem of determining the gradient current pattern in a shallow area such as Georges Bank. It seems clear that the ordinary temperature and salinity data will have to be supplemented by more specialized and detailed observations.

Mr. Woodcock's study of instability at the sea surface and in the lower layer of the atmosphere has continued with excellent results. The general oceanographic significance of his observations is becoming more and more apparent.

STUDIES IN PHYSICAL OCEANOGRAPHY AND METEOROLOGY

R. B. MONTGOMERY

1. Studies of the kinematics and dynamics of the waters in the Straits of Florida were continued. A short report has been published on the sea level difference between Key West and Miami, indicating that its fluctuations do not serve as a useful index of fluctuations in the velocity of the Florida Current.

2. The transfer of carbon dioxide between atmosphere and ocean was investigated.

3. With Mr. Sykes' assistance a table was comupted with the purpose of obtaining more accurate calculations of density from chlorinity determinations.

4. Jointly with Professor Spilhaus, and with the assistance of Mr. Sykes and Mr. Pollak, the preparation of mean isentropic charts of the ocean was initiated.

STUDIES ON THE PIGMENTATION OF FLATFISHES

CLINTON M. OSBORN

During the summer season improvements were made in the techniques used in growing ventral pigment on the summer flounder. Under the most favorable conditions an appreciable growth of melanophores could be detected after 90 hours of experimental treatment. That light is a significant factor in the development of the pigment was indicated in two ways: 1) melanophores failed to develop in areas covered by opaque masks, and 2) melanophores failed to grow on the ventral surfaces of flatfishes kept in total darkness (all other experimental conditions remaining unchanged).

Preliminary denervation experiments indicate that the ventral melanophores develop with equal facility in innervated and denervated areas. This is interpreted to mean that the cells which differentiate into melanophores may do so without stimulation through functional nerve endings.

It is believed that the question as to the origin of ventral melanophores in normally unpigmented areas has been answered by application of the "Dopa" technique. Totally unpigmented ventral scales possess numerous "dopa-positive" cells. Apparently these are the cells which develop melanin *in situ* when subjected to the proper experimental conditions. In nature, however, the ventral integument, although abundantly provided with "Dopa-positive" cells, remains unpigmented due to inadequate stimulation.

CORE FORAMINIFERA FROM THE CONTINENTAL SLOPE

FRED B. PHLEGER, JR.

During the past season additional data have been obtained on the distribution of glacial Pleistocene foraminiferal faunas in the submarine cores, particularly of the Georges Bank region of the continental slope. The faunal work has been put on a quantitative basis and the tabulation of the detailed results is now in progress. The most important tentative result is the recognition of two or more apparent depth zones in the modern, bottom-living assemblage. The interpretation of this result will aid materially in solving problems connected with the Pleistocene history of the ocean, and also the interpretation of marine environments of rocks deposited in the more remote geologic past. The paper now in progress contains data and interpretations on fifty cores, and will be finished in the near future.

During the summer of 1939 it was demonstrated that living pelagic foraminifera could be collected and preserved successfully. This makes possible future investigation of horizontal and vertical distribution of living pelagic types, and this will have an important bearing on the interpretation of the faunas found in all the marine sediments.

CHEMICAL INVESTIGATIONS

NORRIS W. RAKESTRAW

The work on decomposition and regeneration of organic matter in sea water has been continued. The relation of the different parts of the cycle to each other has been studied, and it has been shown that the several stages may proceed simultaneously. A start has been made on the investigation of factors which determine the varying length of the total cycle. The influence of decomposing organic matter upon the dissolved gaseous nitrogen has also been studied, with no conclusive results as yet.

A long-range investigation is also under way to attempt to determine the rate of oxygen consumption in deep sea water, at and below the oxygen minimum layer.

Variations in the gaseous dissolved nitrogen have been followed in stored water over long periods of time, but the relation to other parts of the nitrogen cycle has not yet been definitely established.

OCEANOGRAPHY OF THE GULF OF MAINE

ALFRED C. REDFIELD

During the past season I have prepared and published two papers on the distribution of the plankton collected during a survey of the Gulf of Maine made in 1933–34.

I have also worked on the preparation of a report on the distribution of oxygen in the Gulf of Maine at that time and am making a study of data on the distribution of oxygen in the Atlantic ocean in an attempt to determine the importance of isentropic mixing in the genesis of the layer of minimum oxygen and maximum phosphate concentration.

PHYTOPLANKTON OF GEORGES BANK

GORDON A. RILEY

The first year's work on the phytoplantkon of Georges Bank was largely concerned with the horizontal and vertical distribution of the plankton, and its relations with physical and chemical factors. During the summer months (September, 1939; May and June, 1940) there was a moderately high concentration of both phytoplankton and nutrients (nitrate and phosphate) in the shallow, central portion of the bank, with lesser quantities in the surrounding deeper water. The total quantity of plankton underlying a unit area of surface did not show such a stratification, however. During the January, 1940, cruise the plankton crop was small, showed little horizontal variation, and was concentrated near the surface. The spring diatom burst began in March in the shallow water in the central part of the bank and lasted until May. In the deeper water it began later and did not last as long, but at the height of the diatom burst in April the crop was of the same order of magnitude as in the shallow water.

From statistical analyses of the data it appears that the factors which limited phytoplankton growth on Georges Bank were light and vertical turbulence in winter, and in the summer, nutrients, zoöplankton grazing, and high temperature. The latter exerted a direct effect on the respiratory rate of the plankton and perhaps on flotation, and an indirect effect through its influence on vertical stability and zoöplankton activity. Rough estimates indicate that the mean standing crop of phytoplankton on Georges Bank varied from two to forty grams of carbon per square meter, and the total productivity from practically zero to one gram of carbon per square meter per day.

STUDIES ON FISHES

WILLIAM C. SCHROEDER

1. *The Deep Water Fauna Around Cuba.* The large collection of fishes trawled by "Atlantis" around Cuba in 1938 and 1939 has now been segregated for study and placed in the Museum of Comparative Zoology at Harvard. Some progress has been made on the identifications and descriptions of the sharks and skates.

2. *Migrations of Gulf of Maine Haddock.* A report has been completed based on data obtained during the years 1923–1932.

3. *Fishes of the Western North Atlantic.* In collaboration with Dr. H. B. Bigelow, work was started in the fall of 1940 on the sharks and skates and much progress had been made by the end of the year. Our paper dealing with sharks of the genus Mustelus in the western Atlantic was published in December.

PLANKTON STUDIES

MARY SEARS

1. The reports on the phytoplankton collected in the Gulf of Maine during 1933–1934 were completed.

2. The report on the phytoplankton for the Gulf of Maine as a whole made it clear that the phytoplankton cycle on Georges Bank had not been adequately followed. During the spring (1940), it was feasible to collect phytoplankton samples from this area and these have been studied using the same method as for the earlier collection. The report based on this collection is in progress.

3. The collection of zoöplankton samples along the profile from Montauk Point (or Martha's Vineyard) to the Sargasso Sea (Station B) has been continued, whenever feasible, for the study of the annual fluctuations in the zoöplankton populations of the coastal water and of the annual planktonic cycle of the offshore waters.

4. A collection of plankton made during 1939 in connection with the study of the ecology of the guano birds now being made by the National Guano Administration of Peru has been received for study. In July, the Institution sent two plankton samplers to Peru for use in making further collections.

5. The enumeration and identification of the "Dana" siphonophores has been continued.

INTERNAL WAVES

H. R. SEIWELL

Early in the year two anchor stations were occupied in the axis of the Gulf Stream off Cape Canaveral, Florida, and measurements of temperature, salinity and currents taken continuously over 48 hour periods.

In August I went to the Scripps Institution of Oceanography for a temporary visit in order to complete a statistical and geophysical analysis of internal wave data obtained the previous year in the southern North Atlantic. The results, which among other things, suggest a definite connection between internal wave and tidal mechanisms, will shortly be published.

Since the present international situation may force an interruption of my own research, work on other physical problems in progress last year has been temporarily discontinued in order that summaries and tabulations of the large masses of data on hand could be prepared in forms suitable for future use. A grant from the American Philosophical Society covered assistant expenses for routine computations during the first six months of this year.

During the spring and summer, Mr. Andrew Stergion, while assisting me at the Institution, prepared his thesis for a master's degree in mathematics at Massachusetts Institute of Technology under the joint direction of Dr. George Wadsworth and myself.

PHYSICAL OCEANOGRAPHY OF THE GRAND BANKS REGION AND LABRADOR SEA

FLOYD M. SOULE

During the months of January, February, and part of March, manuscript was completed for the section on oceanography of the U. S. Coast Guard Bulletin No. 29 (season of 1939). Included in this work was an analysis of two profiles of temperature and salinity anomaly to clarify the genesis of the isolated cold water masses frequently found near the Tail of the Grand Banks. Tables of the difference between σ_0 and σ_t for various values of temperature and density, and of σ_0 corresponding to various values of salinity were prepared to facilitate the plotting of lines of equal σ_t on temperature-salinity coordinates. Study of a single survey developed the existence of definite temperature-salinity correlations for the mixed water and Labrador Current water in the Grand Banks region. A comparison between the 1938 and 1939 thermal characteristics of the Labrador Current off South Wolf Island, Labrador, showed an offshore shift of this current

attributed to abnormal winds during the winter of 1938–39. The volumes of flow, mean temperature, and heat transfers of the Current at Cape Farewell were derived from observations made in 1939 and compared with seven previous occupations of the Labrador section and nine previous occupations of the Cape Farewell section.

The months of April, May and June were spent on the oceanographic vessel of the International Ice Patrol Force, the *General Greene*, making topographic dynamic charts of the Grand Banks region. Four surveys resulting in five charts of this area were made,the charts being referred to the 1000-decibar surface and based on 235 oceanographic stations. An additional 21 oceanographic stations were occupied from the surface to as near bottom as was practicable on a short post-season cruise of the *General Greene* along a section from South Wolf Island, Labrador, to Cape Farewell, Greenland, between June 25 and June 29.

A report on the oscillations of the glacier front in Arsuk Fjord, Greenland, covering measurements made by the U. S. Coast Guard between 1931 and 1936 was submitted to the Secretary, International Commission of Snow and Glaciers.

After the return of the *General Greene* to Woods Hole in July, the remainder of the year was devoted to analyses of data collected during the year, and to preparing for publication the oceanographic section of U. S. Coast Guard Bulletin No. 30 (1940 season).

STUDIES IN PHYSICAL OCEANOGRAPHY AND METEOROLOGY

ATHELSTAN F. SPILHAUS

1. A report on the results of a detailed study of the ocean to the depth of 150 meters in the neighborhood of the Gulf Stream was completed and published. The data analyzed in this work were taken on two cruises across the Stream in the summer of 1939. The first section (July 1939) consisted of a stretch of 175 miles with Bathythermograph soundings on an average of every 3 miles taken with the "Atlantis" traveling at full speed. An extremely detailed temperature structure was revealed indicating the presence of eddies of the size of 10 to 15 miles on the northwestern edge of the Stream. The second cruise in the same waters, in August, again showed the presence of eddies of about the size as those observed in July; on this cruise, however, the Pressure Operated Sea Sampler was used with the Bathythermograph and by employing the chlorinities thus obtained the eddies were substantiated by considerations of the temperature-salinity correlation. This work indicated the potentialities of the Bathy-

thermograph and Sea Sampler as oceanographic tools and demonstrated the great advantages of working with the vessel under way.

2. A cruise was completed in September, 1940, for the purpose of obtaining a quasi-synchronous representation of conditions over an area at the edge of the Gulf Stream. For this attempt the Thermographic Sea Sampler (Bathythermograph and Sea Sampler combined into a single unit) was used and about 250 stations were made during the execution of a spiral shaped course covering an area about 400 miles square. Oxygen and chlorinity determinations at seven points between the surface and 150 meters were made at each station. Preliminary analysis of the data points to results of extreme interest.

3. An investigation with Dr. R. B. Montgomery of certain aspects of isentropic analysis in the atmosphere is in progress.

SUBMARINE GEOLOGY

H. C. STETSON

It was found necessary to put in one more summer's field work to furnish more nearly complete data for the study on the sediments of the continental slope and on the seaward extension of the Coastal Plain, which is being undertaken jointly with Dr. Fred B. Phleger. The walls of every canyon from the Corsair Gorge to Norfolk Canyon have now been dredged in many places for outcrops of the Coastal Plain formations and eight that can be identified have been found. Numerous cores have been taken in every canyon as far seaward as they can be traced, as well as in all significant areas on the slopes which lie between. Dr. Phleger's investigations on the foraminifera of the 1939 cores, supported in part from a grant from the Penrose Fund of the Geological Society of America, are ready for publication, but it was thought best to wait until the field work was completed and publish them with my report.

Miss Frances L. Parker has completed her ecologic and quantitative study of the foraminifera of the continental shelf north of Cape Hatteras, and the report only awaits a final revision before publication.

Last spring Dr. M. Juul Hvorslev of the Soil Mechanics Department of the Harvard Engineering School designed a coring tube for us which operates on an entirely new principle. A tripper, operated by a pilot weight which hangs below the coring tube proper, releases it at a regulated distance above the bottom, allowing it to fall freely through the water. The upper end of the apparatus has four steering vanes, like an aerial bomb, and the weight is streamlined. A fall of only eight feet was required to drive the bit into the bottom its full

length of ten feet in any of the sediments encountered on last summer's cruise. This tube, while no more efficient than the Piggot gun, has the advantage of being simpler to operate.

DISSOLVED ORGANIC NITROGEN IN SEA WATER

THEODOR VON BRAND

The method of Krogh and Keys for the determination of dissolved organic nitrogen was tested in view of possible future field work. It was found that in sea water samples stored for a long time in the laboratory the values can be reproduced within reasonable limits of error without great difficulty. In freshly taken sea water the content of dissolved organic nitrogen remains practically unchanged in samples repeatedly analyzed throughout a storage period of about four weeks, provided that at the beginning the organisms had been removed by filtration through a dense glass sinter filter. If the organisms remained in the water, the dissolved organic nitrogen increases considerably. It is believed that the method, if used with necessary caution, will yield valuable results both in field work and in experiments on the decomposition of plankton.

VITAMINS A IN THE EYES OF INVERTEBRATES

GEORGE WALD

The retina of the squid, *Loligo pealii*, contains 1–2 micrograms of vitamin A_1, and about 3 times this quantity of retinene$_1$. No trace of these or other carotenoids occurs in other squid tissues. The vitamin A_1 does not appear to participate directly in the visual processes, since its concentration remains constant in all conditions of light and darkness. Retinene, however, is stored in large amounts in the retina, and in addition is liberated from the photosensitive complex on exposure of the dark adapted squid or the isolated retina to light. Retinene is in this sense the vitamin A of the squid—vitamin A_3. The squid appears to possess the simple visual cycle, visual purple$\rightleftharpoons$ retinene+(protein?).

The eyes of green and fiddler crabs (*Carcinus maenas* and *Uca pugnax*) also contain high concentrations of vitamin A_1. No trace of retinene has been found in these eyes.

There is therefore no discontinuity between vertebrates and invertebrates in the occurrence and utilization of vitamins A in the eye. Previous failures to identify vitamins A in invertebrate tissues may be ascribed to their segregation, perhaps exclusive, within the retinal tissues.

STUDIES IN MARINE MICROBIOLOGY

SELMAN A. WAKSMAN, BOSTWICK H. KETCHUM AND CHARLES M. WEISS

During the year 1940, nine investigators in marine microbiology have spent varying periods of time at the Oceanographic Institution. The Bureau of Ships of the U. S. Navy Department has established a project dealing with the study of the fouling of ships' bottoms, and most of the efforts of this group of workers were devoted to the solution of this problem. Dr. Phelps, who carried out most of the work during the summer, resigned on September 1, but is still associated with the project, carrying on experiments at Port Aransas, Texas.

The problems investigated concern the primary film which forms on surfaces submerged in the sea. The bacteria which form the film apparently do not differ from the normal population of the sea water, except in their ability to adhere firmly to a surface. Several types of bacteria have been isolated from panels exposed at Woods Hole, and studies of their physiological nature are being made.

The rate of formation of the films, and the amounts of organic and inorganic substances present in the films differ greatly at various times of year. As would be expected during the colder winter months the films formed slowly, whereas in the summertime the films formed very rapidly. The rate of formation of the film is closely related to the population of bacteria in the water at any given time. It is, therefore, influenced by the nature of the water, latitude and environmental conditions. The rate of formation of the film and its chemical composition are also influenced by the nature of the surface exposed.

Preliminary experiments indicate that the presence of the primary film on painted surfaces interferes with the attachment of barnacles and other macroscopic fouling organisms.

In addition to this project several other problems pertaining to the microbiology of the sea received consideration. It is sufficient to mention the work of Dr. C. Hock on the chitin decomposition by marine bacteria, and of P. Souder on the various types of bacteria found in sea water and in the sea bottom.

DIRECT MEASUREMENT OF CURRENTS

E. E. WATSON

Two short cruises were made for experiments on anchoring the ship and on the use of the recording current meter. On the first cruise the ship was anchored in 1500 fathoms, using a 300 lb. mushroom anchor and 240 ft. of chain, weighing about 600 lb., shackled to a

swivel on the end of the main ship's cable. The action of the chain was satisfactory, but the small mushroom was quite inadequate to keep the ship from dragging. A much larger mushroom or some other type of anchor will be necessary. Current measurements made from the ship while drifting freely on a calm day showed that at each depth the current is remarkably steady. Trouble with the meter circuit developed at depths of 400 meters or more, due to breakdown of the transformer oil into hydrogen and carbon by the tiny spark at the contact breaker in the meter. After various experiments to cure this trouble a type of snap action contact breaker with ratchet drive was designed and built into the meter. A damping disc was built to hang on the cable above the meter and in conjunction with the elastic suspension on deck this minimized the vertical motion caused by the roll of the ship.

The second cruise was made the first week in September, immediately after a storm. A hydrographic section run south from Georges Bank into deep water showed clearly the encroachment of warm Atlantic water onto the southern slope of the Bank. The meter was tested again in deep water and operated satisfactorily with the full 750 meters of cable out, but owing to strong winds there was a considerable wire angle and the actual depth of the meter was uncertain.

In the laboratory a simple towing truck was built for calibrating meter propellors in the tank room.

During the summer Mr. John Dobson assisted in all of the above work.

BOTTOM FAUNA OF GEORGES BANK

GEORGE C. WHITELY, JR.

Meter stramin-net bottom collections made in 1939–40 during winter and spring cruises of the "Atlantis" provided material for examination. In order to find what to expect from the tows, the first that had been made on Georges Bank since 1872, a dozen bottles from each cruise were examined. This preliminary investigation showed that about 18 Amphipod species, 9 Schizopod and 6 Decapod were numerically important.

Detailed numerical analysis of the collection was then begun.

List of Contributions

LIST OF CONTRIBUTIONS

FROM THE WOODS HOLE OCEANOGRAPHIC INSTITUTION

For a list of Contribution Numbers 1 to 100 see previous issues from 1933 to 1940. A separate list of these numbers may be obtained on request.

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